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SEA—INSIDE

BEING THE STORY OF SEA WATER—WHERE LIFE BEGAN—WHERE LIFE ENDS

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"ONCE upon a time" (according to a legend which every history primer told in the days before primary education became secondary), King Canute of Danish England, to impress his warriors with the limitations that even a king must acknowledge, had his royal chair carried to a beach nearby, where the great North Sea flung its angry waves against a sandy slope.

"Stop!" commanded the king—and exactly as he expected it, the sea spat spray in his face and sand slid in his sandals. And accordingly, and ever since, Englishmen the world over, on the slightest provocation, sing "Britannia, Britannia—Rules the Waves."

In any event a king's attempt to stem an angry tide and to address the sea resulted in a ducking.

And somewhere in the literature of the so-called popular science, I came across another salute to the sea—penned by a word-wild chemist. Here it is:

> Oh, Sea, Thou saline and undulant aqueous solution of halides, carbonates, phosphates, sulphates, and other inorganic compounds. What mysterious colloids are dispersed within thy slightly alkaline bosom? What silent and unseen reactions vibrate in dynamic equilibrium, constantly destroyed and instantly restored, among thy unnumbered oscillating molecules? What uncounted myriads of restless ions migrate perpetually throughout thy tentatively estimated volume? What unguessed phenomena of catalysis, metathesis, and osmosis transpire in thy secret fluid profundities under increased pressure? What cosmic precipitates descend in countless kilograms upon thy argillaceous gelatinous, siliceous, diatomaceous and totally unillumined bottom? In short, most magnificent reservoir, what is thy flow-chart and complete analysis?

Which to my way of thinking seems to invite more of a drowning than a ducking.

Yet, in this bucketful of words, are reasons galore why the subject of this presentation can not in the compass of space available to it, find else than perfunctory treatment.

And so, with a guarantee that the subject will be treated in such wise that its depths will not be sounded, nor its surface sailed so tediously as to nauseate the most tender minded—let us, together —even when hope for a brief dissertation seems gone—sail on—sail on.

Shakespeare's sea dirge seems a most appropriate starting point:

> Full fathom five thy father lies;
>   Of his bones are coral made;
> Those are pearls that were his eyes:
>   Nothing of him that doth fade
> But doth suffer a sea-change.
> Into something rich and strange.
> Sea nymphs hourly ring his knell,
> Hark! now I hear them—ding, dong bell.

And the Bard of Avon, although he may have been neither a chemist, nor a biologist, in the modern acceptance of terms—was certainly an inspired, understanding interpreter of the origin and destinies of the material make-up of every living creature that has ever existed on this planet called earth. For it is from the sea that all living matter came—and the sea will at last inexorably demand the solubles of all the dead's dissembled residues whether it be by the short route of Shakespeare's, or by the longer road suggested in Bryant's "Thanatopsis":

> Old Ocean's gray and melancholy waste
> Are but the solemn decorations all
> Of the great tomb of man.

We shall not of necessity go down to the sea in ships—but certainly in chips—of molecular matter, borne to the ultimate solution of all our griefs, and wrapped in a blanket of water.

The Solution of Life and Death

Water preceded life on this planet. That is obvious—and reasonable, for where there is no water there can be no life. No matter whether life elects to serve its time in the simple, single-celled amoeba, or in the trillion-celled, complicated and conceited creature called man—short indeed would be its stay unless it had the varied services of its versatile ambassador—water. Life comes to us wrapped up in water, and death, so often the solution of all our problems, is also always a water reaction. Indeed, water gets us even after death, for it is largely through its agency that nature uses our substance over again in the fabrication of other creatures, so often improvements over the originals. And in this solvent cyclic scheme the sea is most important.

But, asks some one, whence came the sea? And the answer is easy if the imagination is elastic. According to that great group of guessers, the nebular hypotheticators, headed by the great Frenchman LaPlace, the earth was once devoid of water.

Diffident Drops of Rain

All one has to do is picture this world primordial—let us say a billion or two years ago—a hot ball of matter, broken here and there with fissures from which issued streams of molten rock. The original thin atmosphere has enlarged, and finally there has come a time when the water vapor produced by the electric union of hydrogen and oxygen arrives at dew point—and down come the first diffident drops of rain that this world ever knew.

And what a hissing, steaming reception the gigantic cauldron called earth afforded this first aqueous visitor. Back to the sky the water molecules scamper, there to await until the cold dome of heaven again condensed them into a cloud.

Cloudburst after cloudburst fall like Chinese regiments, and earth is a vast distillery. At last, however, heat gives in and water gains its victory. The skin of the earth is cool, and water remains in its cavities. Hot, muddy puddles grow to dismal ponds, and ponds to lifeless lakes—the lakes in turn become the dank primeval seas, and the seas the heaving oceans.

And yet no life.

Not a single blade of grass—not a creature on the land or in the churning water—nothing but bare, hot rock, hissing, crackling, crumbling, underneath relentless showers. Fire and water are the only busy realities—and fire is now the slave and servant—and water monarch of all it surveys.

Then came Life.[1] Just how—just

[1] E. E. Free, writing in the *Forum* about the generation of life, states: "We can now calculate what was the composition of the air and of the ocean when in the course of time the earth became cool enough to hold a watery ocean at all. The air contained no gaseous oxygen as it does now. All the oxygen had gone into chemical combinations. Whether the air con-

when—just why—no one seems to know. But certain it is that water mothered all things living. Certain it is too, that some day—far away—water will leave the earth again—and leave it like the moon, a cold and lifeless ball.

Dr. Lowell, the famous astronomer, went so far as to describe the agonies that our descendants would suffer, and the tremendous irrigation schemes which they would of necessity devise as their water supply grew less and less. Possibly the canals and waterways in Mars are evidence of such a current calamity in that far distant planet. This, of course, somewhat discounts Tennyson's song of water, which ends with "For men may come and men may go, but I go on forever."

The Bible is much less verbose in its explanation of the birth of the sea. For in Genesis 1: 10 we read—"And God called the dry land earth, and the gathering together of water called He Seas—and God saw that it was good!"

But the first sea-water was fresh water, free of its present plethora of solubles, and certainly lacking in salt. Yet knowing the hunger of water for that which is substantial, solid and soluble, it is easy to surmise how soon the sea came to be briny and as full as it is of something of every element.

From the first fresh water of universe to the present state of the sea is a tremendous development. Contemplate, for instance, upon this estimate of chemical content of just one cubic mile of old Atlantic's waters, as compiled by some professor who prefers this sort of dabbling arithmetic to teaching horse sense to his classes. Here it is: 128,284,403 tons of sodium chloride or common salt; 17,946,522 tons of magnesium chloride; 358,270 tons of magnesium bromide; 1,400 tons of fluorine combined as fluorides; and a minimum of 90 tons of iodine combined as iodides; to say nothing of the thousand and one other solids contained in lesser proportions.

Indeed the composition of the sea[2] is as

tained any gaseous nitrogen is uncertain. What it unquestionably did contain was carbon monoxide, the deadly gas,—existing in the exhaust of automobile engines—and prussic or hydrocyanic acid. In the primitive ocean, having absorbed gases, and therefore full of deadly prussic acid and overlaid by an atmosphere containing large amounts of a poisonous gas no less deadly, the first life arose. It is reasonable to assume that there occurred some natural chemical synthesis of glycocoll or of a similar material. Glycocoll is the simplest amino acid, composed of four elements, oxygen, hydrogen, carbon and nitrogen obtained either by destructive treatment of protoplasm with caustic chemicals, or by a succession of chemical reactions between the three substances of the primeval ocean mentioned: prussic acid, carbon monoxide and water. During the three or five billion years which were to elapse before the period when we find actual traces of life in the rocks, there was ample time for such simple substances, as glycocoll, to undergo additional chemical changes and combinations and to be built up into more complicated forms perhaps at last into substances equivalent to our modern protoplasm."

[2] The composition of ocean water differs in various parts of the world. Generally speaking, it is less concentrated near the shores because of the influence of fresh water rivers. The following is an analysis of the water in the English Channel ten miles from the coast of France, which had a specific gravity of 1.026 at 15° C.

Gaseous contents	In one kilo. liters	In one liter. liters
Atmospheric air	0.0120	0.0123
Free carbonic acid	traces	traces
Free hydrogen sulfide	traces	traces
Solid contents	Gm.	Gm.
Potassium chloride	0.09763	0.10019
Sodium chloride	26.09300	26.78913
Lithium chloride	0.00042	0.00043
Ammonium chloride	0.00178	0.00183
Magnesium chloride	3.19300	3.27700
Sodium iodide	0.00920	0.00944
Sodium bromide	0.10605	0.10882
Magnesium bromide	0.03084	0.03163
Calcium sulfate	0.09017	0.92540
Potassium sulfate	0.00919	0.00943
Sodium sulfate	2.57250	2.64012
Magnesium sulfate	0.32736	0.33597
Magnesium phosphate	0.00046	0.00047
(Ammonio-magnesium) phosphate	signs	signs
Calcium carbonate	0.13600	0.13959

A—Sea. B—Pool. C—Gate. D—Trenches. E—Salt basins. F—Rake. G—Shovel.

SALT FROM OCEAN WATER
AGRICOLA'S "PROCESS."

complicated as the composition of the land that it covers, and of the silt and soil that surrounds it—for it is natural that a share of every substance on and in the earth must sometime find the sea.

Magnesium carbonate	traces	traces
Iron carbonate	0.00021	0.00021
Manganese carbonate	signs	signs
Silicic acid	0.01420	0.01457
Organic matter	signs	signs
Pure water	966.50646	991.91577
Total	1000.00000	1026.30000

Further out from shore the proportion of sodium chloride may rise to 36 or 37 parts per thousand. In inland seas the proportion of salt is often very much greater than that of the ocean, thus the amount of solids in the water of the Great Salt Lake of Utah has varied between 15 and 20 per cent., while in the Dead Sea of Palestine there is 27 per cent. of solids.

How little understanding of this important fact is found in the words of another poet who has taken every adjective out of universe leaving this barren bit of pouting poetry:

The earth is just a lot of dust,
The sky's a lot of air,
And the sea's a lot of water
That happens to be there.

What a fool's philosophy is reflected in the words and what a monument to ignorance. For in the salt of the sea alone is sufficient romance of origin and diversity of use, to intrigue not only those who write, but those who also think.

Salt, or sodium chloride as the chemist calls it, is a benign alliance of two malignant elements, sodium the swashbuckling, arch-enemy of water, and chlorine, the green-eyed ugly gas, so poisonous to life that the god of war himself has used it as a mighty weapon. Yet when wed, these toxic devils lose their elemental fury, and lead a useful, mild existence.

The physical properties of salt bespeak its mild-mannered meekness. Soluble in water, non-toxic in moderate amounts, non-combustible and stable to a high degree, it becomes one of life's most valuable servants. Without its competence of salt the animal body would soon be derelict, for as we shall later prove, every living cell in that busy tissue called blood must have its share of salt to enable it to keep life's fires burning.

Yet by the same token, salt in excess is a violent poison, and in China suicide by salt is said to be a much maneuvered means to an economical end. Shipwrecked mariners know full well the menace of drinking sea water—though sea water runs in their veins.

But how or why came the salt of the sea is another moot question. In Child's "Geology" of 1832 we are told that "He who formed the earth and the sea knew that by saltness only could the ocean be kept sweet and that this saltness is abso-

lutely necessary in order to preserve the ocean from putrefaction." And this is not as childish as it sounds.

If it is true that the earth was formed by the gradual cooling of a molten mass, it is reasonable to suppose that the primeval ocean formed out of an atmosphere of water vapor was fresh-water ocean. Then by the incessant weathering and solution of the rocks the salt has been leached out and has accumulated in the ocean from which there is no outlet for its surplus material, except for its volatiles which go back to the atmosphere by evaporation. There are some who believe that much of the salt in sea water is actually produced there by interaction between sodium sulfate and calcium chloride, both of which are carried into the sea by the rivers that constantly feed it. By a merry exchange of acid radicles the calcium chloride is converted into the less soluble calcium sulfate or gypsum, which sinks to Davy Jones's locker, and the sodium sulfate into sodium chloride or common salt, which gives the sea its salty sweetness. Such a process is a very simple, yet a very certain bit of chemistry.

And millions of years of continuous washing and bleeding of the solubles of earth to the sea have taken their toll from the land, exactly as the land has, at times, taken its toll from the sea.

The Sea Caught Napping!

For in the hectic, heaving changes that have come to the surface of earth, the sea has more than once been caught napping. During such upheavals, sections of ocean have been cut off by the careening land, to form isolated salt lakes. The sun has dragged the water from many of these lakes, leaving large deposits of salt and other soluble substances. Some such deposits are found right on the surface of the earth and others are underground, having been covered by more recent formations.

In other words, what man is doing to-day in isolating tracts of sea-water and separating the salt by solar evaporation must have been practiced by nature on a large scale throughout the ages. The alternating layers of salt and clay that are found in some rock-salt deposits are explained by the fact that the clay represents the mud that was brought into the lake during the rainy seasons.

The immense salt deposits of Utah and Nevada were once the beds of prehistoric salt lakes, and so is our famed Great Salt Lake the remains of a large inland sea that once covered that particular area. Should the climate become drier than it is now the shrinkage of the Great Salt Lake, which has been going on for ages, will continue until a huge salt deposit remains.

All over the earth tremendous deposits of salt attest to the drying up of pieces of the primeval oceans, and somewhere in the Carpathian mountains is the most noted of them all.

The Chamber of Commerce of Weilicza, where these salt mines have been worked since the eleventh century, proudly announces to the world that the unworked deposits are still 500 miles long, 30 miles wide and nearly half a mile deep—which comforts one with the thought that although all the coal and the oil of the world will some day be depleted, there will always be salt enough to season our soups and to keep our Sunday mackerel sweet and wholesome. But enough for the moment of such landlubber reflections, and let us hie to the sea again.

Now there are so many seas—good seas and bad seas, deep seas and shallow seas—blue seas and black seas—live seas and dead seas—that for our specific pedagogic purpose here, we had better select just one—row with courage to its very center, and then with one gargantuan splash, plunge, eye-open, to its saline cellar.

THE SEA YOU SEE IS THE DEAD SEA

You are now in Palestine, and in deep water already. The sea you see is the Dead Sea—the saltiest sea in existence. It is deliberately selected as our sample sea because it is different, and because the world strangely owes it an apology. Maligned for centuries by people who did not understand its real character, called "Dead" because it is so heavily loaded with mineral salts that nothing living seeks its waters—charged with evolving such a miasmatic vapor that even sea-gulls are sea-sick when they essay to cross it; reported as being so buoyant with salt that those who sailed it never carried the customary life savers—such has been the reputation of the so-called "Dead" Sea. Even the climate of the valley where it sullenly rests is reported in old travelers' tales as dreadful and deadly.

But the old "dead" sea was only "playing possum." Within the last few years so many things have happened on its shores, and so many age-long beliefs disproved, that "the Dead Sea to-day is a thing of life, pulsating with health and conferring benefits on thousands of human beings." These are the words of Major T. G. Tulloch,[3] upon whose recent lecture before the Royal Society of Arts in London, England, these paragraphs are freely drawn.

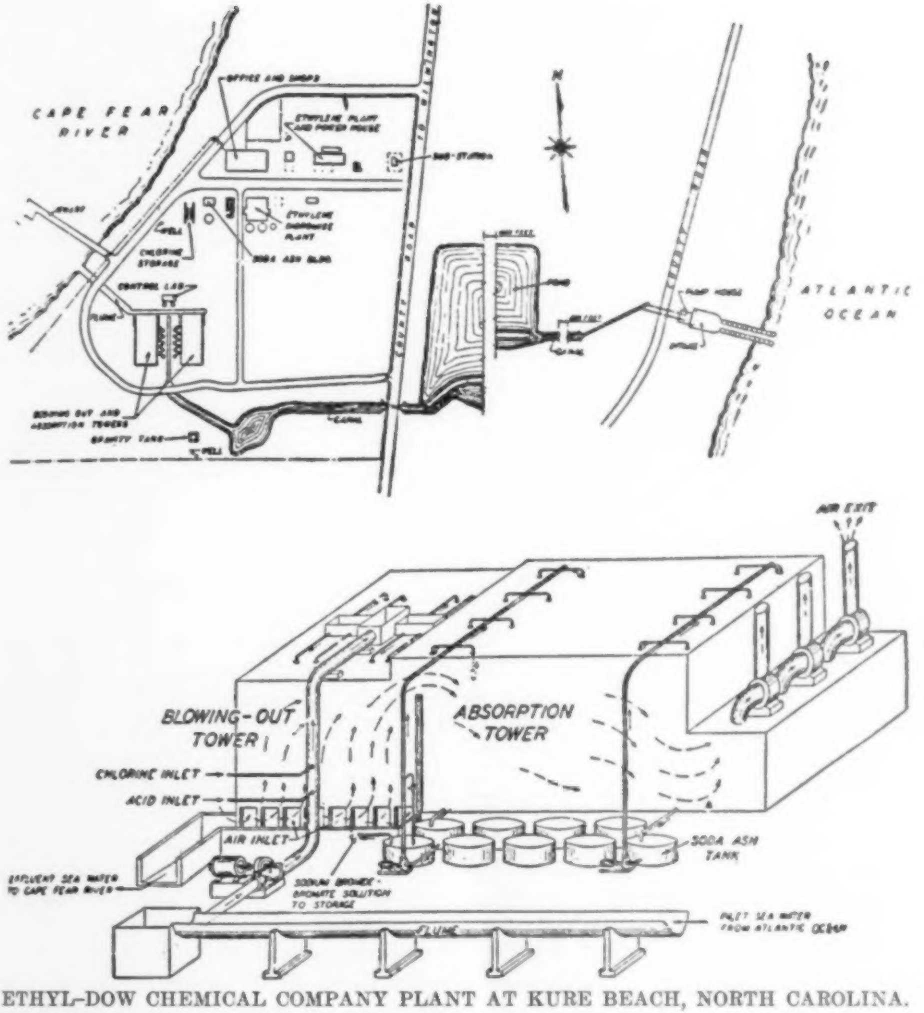
Palestine is governed under a British mandate, and Major Tulloch and his associates being Britishers have readily secured a concession to exploit the possibilities of the Dead Sea after numerous analyses had convinced them that its waters were a vast potential source of common salt, potash and bromine. They organized Palestine Potash, Limited, which started practical work in 1930. The astonishing progress made since then amply confirms their judgment, and proves that man at last has been able to do what the crab, the skate and the lobster have done ever since their origin—namely, to grab and grasp for their own the chemicals that exist in the sea.

As the fresh water from the Jordan and other streams dilutes the surface water, sounding experiments were made which showed that the salinity increased in proportion to the depth, until at something like 200 feet a constant analysis was noted. A 30-inch pipe line, 2,800 feet long, was therefore laid out from the shore to approximately this depth, and pumps provided which discharge into an open canal. Along the shore and encircled by the canal, great evaporating pans covering thousands of acres were constructed. Most fortunately for the success of the venture the local soil, which is alluvial clay, proved impervious to leakage, since a porous soil would have involved an enormous expense in pan construction.

The pans are about two feet deep, and the water from the canal goes first to the upper series of pans. Evaporation is by the sun's heat, assisted by the steady breeze which blows all day from the south and all night from the north for most of the year. As evaporation proceeds, the concentration of salt increases, until the least soluble of them, namely, sodium chloride or common salt, is first deposited. The liquor is then run into the next lower series of pans, where, under continued evaporation, the double salt of magnesium and potassium chlorides known as "carnallite" is thrown down. The remaining liquor from these pans is heavy with magnesium bromide, from which bromine itself is separated easily. Potassium chloride, 98 per cent. pure or better, is separated from the carnallite by washing with fresh water.

The important part which the mineral resources of the Dead Sea are destined to play in the world's economics is indicated not only by reason of the simplicity

[3] From Arthur D. Little's *Industrial Bulletin*.



ETHYL–DOW CHEMICAL COMPANY PLANT AT KURE BEACH, NORTH CAROLINA.

of their production, but also on account of their vast quantities, which, computed to close limits, are as follows:

	Millions of Tons
Magnesium chloride	22,000
Sodium chloride (common salt)	11,000
Calcium chloride	5,000
Potassium chloride	2,000
Magnesium bromide	1,000

Moreover, it is estimated that an additional 40,000 tons of potassium chloride is brought into the sea each year by the streams flowing into it.

Major Tulloch calculates that if potash from no other source were available the quantity existing in the Dead Sea would supply the world's requirements for over 2,000 years, and by that time your potash and mine will have sailed the seas again.

Shipment is made by motor truck to Jerusalem, twenty-five miles away, and thence by rail to the docks of Haifa, some 115 miles in all.

Astonishing as are the values revealed

by this development, the present status of the Dead Sea as a health resort is even more remarkable in view of its previous sinister reputation. Major Tulloch tells us that the company has been at work continuously, summer as well as winter, for over four years, and there has not been a single case of illness among the several hundred workmen, though many of them came from cold northern climates. Last year a seaside and health resort named Kallia (which is Latin of a kind for potassium), adjacent to the potash company's works, was opened on April 30, and was patronized by hundreds of visitors daily all through the summer; and on one occasion, in the middle of July, no less than 2,000 vacationists came to dance to the tunes of a local Ben Bernie, and to bathe in the light of the Zion moon.

The Live "Dead Sea"

The remarkable healthfulness of the northern shores of the Dead Sea appears to be due to several factors, one of which is the unique fact that at 1,300 feet below sea level the air is so much denser that 6 per cent. more oxygen is brought into the lungs at each breath than is the case at normal or sea level. There is, moreover, an absence of fogs and an extraordinarily clean, pure atmosphere. Added to this are the stimulating and energizing effects of bathing in the densely saline waters of the Dead Sea.

And better than anything else, so we are informed, bathing frequently in this buoyant sea has a beneficent dwindling action upon those, who having honestly won their cream puff figures, mostly by exceeding the feed limit, hanker after streamline design and a greater girth control.

Another clever and spectacular British achievement is a process originating in Teddington, England, and described in a recent bulletin of the Arthur D. Little research organization:

With this new development it has been found possible to pass ocean water through a succession of filters which entirely removes its salt content. Salt dissolved in water may be considered as a mixture of equivalent amounts of caustic soda and hydrochloric acid intimately mixed. In the English process, the salt solution is passed through layer number one, which absorbs the caustic soda, then through layer number two, which absorbs the hydrochloric acid, then through a similar pair of layers to repeat the process on what may have escaped the first stripping. In this way, by removing the two parts separately, salt can be eliminated, whereas there is no analogous method of removing the chemical sodium chloride (salt) as a unit, all at once.

Perhaps the most interesting part of the English method is the nature of the absorbents used, which are not mineral, but are synthetic organic chemicals of the formaldehyde resin type. The base-absorbing resin is prepared from tannin and formaldehyde, and the acid-absorbing resin from aniline and formaldehyde. Regeneration is possible, so that a cycle can be maintained. So far, the economics of the system have not been investigated, but *Chemistry and Industry*, the British periodical, has a real enthusiasm for the possibilities for this process which "was the work of an ordinary Englishman working in a British Government Laboratory." Perhaps "ordinary" should be qualified a bit in view of the result achieved.

And now for a sea-swing closer to home—and a real story of modern enterprise. It has been said by an English physicist whose recorded dreams are his profoundest gifts to science, that the released atomic energy from one bucketful of sea water would provide power enough to dynamize the whole world's mighty fleet of ships. But he did not envision the reality nor enlighten us as

to how that energy might be secured to put to work.

To the Sea for Power

Not so, however, with the diligent chemists of America, whose more practical minds sought to get from sea water that which it would less grudgingly give.

For instance—when the automobile became a democrat, and its owner a plutocrat, the old-fashioned fuel would hardly suffice for so sensitive and speedy a driver. The high compression motor growled and grunted with every explosion of gas—and something had to be done to stop it.

Along came Ethyl—tetra-ethyl lead—and ethylene dibromide—in the manufacture of which bromine was most essential. Added to gasoline these chemicals silenced its knock.

Bromine and Gasoline

Now bromine is sister to chlorine, and with the rest of the haloid quartette, fluorine and iodine, spends most of her time out at sea. Ten years ago, a paltry two million pounds of bromine sufficed to fill the medicinal and industrial needs for this element and its compounds, and they made it mostly from inland bitterns and brines.

But when the anti-knock craze hit the producers of motor fuel the usual sources of bromine were totally inadequate. And so to sea the chemists went—and so successful was their queer quest that ten times two million pounds of the stuff now annually come from the sea. Mind you, this is in spite of the fact that only four grams of the element are contained in every gallon of brine.

The Ethyl Gasoline Corporation and latterly the Dow Chemical Company, at the mouth of the Cape Fear River on the Atlantic shores, beyond a promontory that keeps the sea from river dilution, have a magnificent modern plant which pumps a billion gallons of sea a day through its vast extracting processes. The bromine is dislodged from its nautical partnerships by the use of chlorine, its zealous sister, a displacing technic familiar even to freshmen. In this way 15,000 pounds of the vicious element bromine are daily claimed from the sea. For the time being other substances are not recovered, although a special research is now under way to broaden the scope of the work.

Once it was thought that sea water was a simple solution of salt. Modern analyses, however, reveal its much greater complexity. Out of the ninety-two known elements, forgetting for a while the dizzy isotopes recently brought to confound an already confounded chemistry, thirty-two separate elements have been separately identified in sea water. Many of them occur in such small quantities that their presence can be revealed only by the spectrographic analysis.

For a long time there was a tendency on the part of the chemist to disregard the importance of those substances which are found in the sea water in minute amounts, but recent discoveries in the physiology of nutrition have taught us to pay more respect to them. We know to-day that iron, copper, manganese and iodine are necessary for the normal functioning of our bodies. Traces of silver and gold and radium are also found in sea water. More radium exists in the mud of the sea than in the ordinary rocks of dry land, Dr. Robley D. Evans, of the University of California, has found. His tests show that radium is being deposited constantly by ocean waters. There is no hope of mining sea mud for radioactivity. Dr. Evans made his experiments merely to test his new method of detecting extremely minute amounts of radium and radon gas emitted by radium. Each ounce of mud contains three trillionths of an ounce of radium.

And who knows but that this radioac-

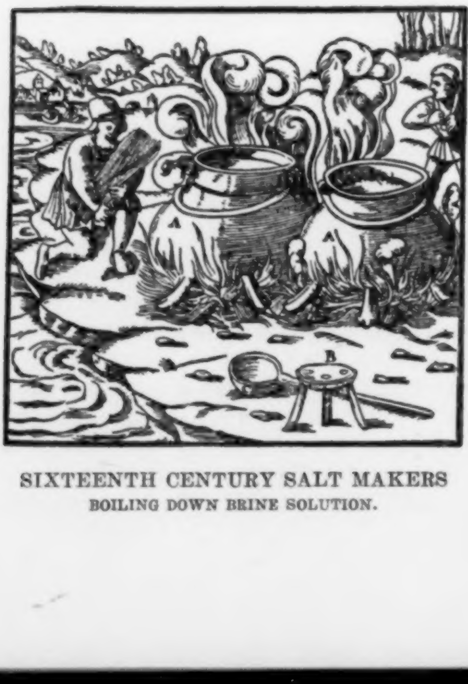
tivity has much to do with the teeming, pulsing life of the sea, that undetermined something that grants the sea its great fertility. The triple play—Shakespeare to Hamlet to Horatio—"There are more things in heaven and earth than are dreamt of in your philosophies"—must contemplate the sea as well—for as yet the secrets of the sea are only half divulged. For there is a vital-energizing force in sea water that is beyond its chemical content.

Home-made Seas

Artificial sea water may be manufactured, and it has been used more or less successfully for a number of years for inland bathing purposes.

But such waters have not been found suitable for fish. Whether this is due to the absence of certain chemicals, normally present in natural sea water in minute amounts, or because the water is not "alive," is still as much a mystery as it has ever been.

That there is still something else to be discovered is indicated by substantial evidence. It is known by fish culturists that comparatively large quantities of artificial sea water become quite suitable for fish after a very small quantity of natural sea water has been added and it is allowed to stand for a week or so. The water apparently becomes "alive," as opposed to the "dead" water which results when the various chemical constituents of sea water are dissolved in fresh water.



SIXTEENTH CENTURY SALT MAKERS
BOILING DOWN BRINE SOLUTION.

Crystalline sea salt of commerce, or the salts obtained by evaporating natural sea water, when dissolved in fresh water, likewise do not produce a water that is "alive," and the water prepared in this manner is practically always inferior to that prepared from chemicals.

Aquariculturists who wish to manufacture artificial sea water can have a druggist prepare the following formula: Sodium chloride (U. S. P.), 36¼ ounces (troy weight); magnesium chloride (C. P., crystallized), 10¾ ounces; magnesium sulfate (U. S. P.), 4½ ounces; calcium sulfate (C. P., anhydrous), 1⅝ ounces; potassium sulfate (N. F.), 1 ounce; magnesium bromide (C. P., crystallized), 2 drams; and calcium carbonate (U. S. P.), 1¼ drams.

This composition should be dissolved in about nine gallons of spring or fresh river water, and then sufficient water is added until the specific gravity, which is determined by means of a hydrometer, is between 1.030 and 1.032, the range which most fish prefer.

While water of approximately the same composition has been used with a certain amount of success in a number of public aquaria and laboratories studying marine life, if a small amount of natural sea water—about one gallon to ten of artificial water—is added and it is allowed to age for a period, the results are very much better.

The Noble Metals

It has been estimated that there exist dissolved in the sea 13,300 million tons of silver, and a cubic mile of sea water is said to contain nearly a hundred mil-

lion dollars worth of gold, which despite a giddy government's attempt to corner that coveted metal, is as yet as useless a gold as the gold that gilds the goldfish. And though the actual gold content of the sea varies from one to three ten-thousandths of a grain to the ton[4] some day—and perhaps not such a faraway day, this metal of metals will be mined from the sea. Fritz Haber, the German chemist, who successfully mined the air for niter, failed to practicalize the claiming of gold from the sea—but some day a Scotchman may do it. Indeed Dr. Stewart (whose name suggests a Caledonian origin), of the Dow Chemical staff, operating the sea water bromine plant in Carolina, specifically states that "now that the recovery of bromine, which is present to an extent of less than four grains to the gallon has been successfully executed, it does not seem beyond reason to expect the chemist of the next decade to extract gold from sea water commercially."

Midgley, vice-president of the Ethyl Corporation, is not so enthusiastic, however. This is his reaction.

> There is a much bigger problem associated with sea water upon the solution of which depends the future welfare of millions of people. This problem is the commercial extraction not of gold or of bromine but of water itself from sea water. No one can say that water is present in too small a quantity to be recoverable. The present price paid for water in arid lands for irrigation purposes indicates that the value of the water in sea water is about the same as the value of the bromine at present prices.

And now let us turn for a while to some livelier aspects of the sea. Let us get personal—admitting a lot, but imagining more.

[4] Since Dr. Haber published his analyses, new quantitative analytical methods have been developed and applied. That variations in concentrations exist seems beyond dispute; however, one does not need to locate such a proposed extraction plant at the points of low concentration. Hence the minimum concentrations reported are beside the point. It is only high concentrations that need be considered as pertinent and Dr. Haber himself reported sample concentrations up to 8 parts per billion.

HOPPER-SHAPED SALT CRYSTALS
DRAWN AFTER A FIGURE IN THE PENG-TZAO-KAN-MU, OLDEST CHINESE TREATISE OF PHARMACOLOGY AND PHARMACOGNOSY, WRITTEN 2700 YEARS BEFORE CHRIST WAS BORN.

Evolution we define as change, than which there is nothing more permanent. The evolutionist acknowledges the unceasing change that goes on in cosmos, earth and life. For him the everlasting hills do not endure; he knows that the continents lift and subside; that the very elements of which earth and suns are made are forever transmuting themselves. Energy as well as matter—is shifting from one form to another. Nothing is static in the inorganic world; nothing is fixed. And man's climb first to the top of his Simian roost, and down again to his present two-legged state, has been a long and arduous achievement.

Evolutionists claim that all life was once marine or submarine—that the antecedents of every creature now living, originally like Venus, came from the sea. And there are many evidences about which incline to prove their story—although a question they have not been quite able to answer convincingly is where the sea secured its life.

Sea Inside

One of the slender threads wherewith they join their arguments is in the remarkable comparison which they make between animal blood and sea water. When blood is permitted to coagulate, the clear, rather colorless serum or plasma which separates, has, exclusive of its protein content, a composition very like that of sea water. It contains so much sodium chloride—so much phosphates—and carbonates—and so much combined iodine—in a ratio similar to that of sea water.

The contention is that whereas we were once limpid jellyfish that floated lazily on the dark primeval seas—we are now so evolved and involved that a share of the sea floats diligently within us, with an ebb and flow in every heart beat.[5]

Certain we are that life in us could not get along without the sea elements that race in our blood stream. Lacking the little salt that parades its molecules constantly—through sleep and waking periods in us—no longer would life remain intrigued.

Blood, lost through hemorrhage, may not be replaced with distilled water else the recipient dies—but the injection of an artificial sort of a sea water, which the Pharmacopoeia calls "Physiological Salt Solution" is a safe procedure.

This aqueous solution contains slightly less than 1 per cent. of common salt (0.85 per cent.).

Red blood cells are dissolved to death by pure water. By salt solution they are kept whole and alive.

States an old Welsh proverb in a much clumsier English dress: "Salt brings balm to every human woe—but it must be as salt of tears, as salt of honest sweat—or as salt in the heart of the sea." The old Welshman whose nimble tongue and nimbler wit composed this Cambrian proverb could hardly have known that the salt of tears, the salt of sweat, the salt of blood and every body salt are cycled from the sea.

Salt is eliminated in all our body secretions. The average weight of salt consumed by sensible persons is about one-half ounce a day. Only a little more than one sixth of this amount is retained as necessary to bring the acid to our gastric equipment, and for other uses, the rest of it being eliminated. Thus there is a ceaseless cycling of salt from the quick to the dead, and back to the quick again. It is for this reason that drinking water containing an abnormally large amount of chlorides is looked upon with suspicion, unless the presence of these chlorides can be explained on other than a sewage basis.

[5] It will be observed that the cells of the human body are aquatic, since they live as small groups or communities in a watery environment regulated by the blood stream and their own individual efforts. The human beings of the body politic, on the other hand, are outwardly terrestrial and live on dry land. But, thanks to Darwin and the others, encouraged and strengthened by spirited opposition to their views, it is now generally accepted that we humans have developed from animals who were inhabitants of the ocean. All these ages we have carried parts of the watery environment with us. Those who by chance read these words do so by looking through thin films of salt water supplied by the lachrymal glands. If these vestiges of the original watery environment of the body politic were allowed to dry up blindness would ensue. They may throw the book away with a sigh of relief, in which event they find momentary refreshment by increased absorption of atmospheric oxygen, again through a thin layer of salt water lining their lungs. Later on, they may listen with approval to criticisms of the wild ideas expressed in this paper; but they can do so only by using little bodies of salt water which constitute essential parts of their inner ears. Our forgotten ancestors learned to see and to breathe and to hear in salt water and we must perforce do the same, so that we are at least partly aquatic. To express it differently, the surfaces of our bodies in contact with air are all coated with dead cells (skin, hair and finger nails). The surfaces, external and internal, made up of living cells (cornea of eye, inner ear, lungs, digestive, urinary and reproductive tracts) are all wet, *i.e.*, aquatic.—Scientific Monthly, 42: 246, 225–226, March, 1936.

Why Thirst?

And every one knows that salt is essential to the welfare of the animal body. It has been shown that animals wholly deprived of it will weaken and eventually die. Indeed, there are few things more distressing than the salt hunger that comes from an insufficient amount of salt in nourishment. One of the chief functions of salt in the body is to provide the proper concentration for the blood serum. It seems that the proper functioning of the body depends upon favorable conditions of osmotic pressure. In order to maintain these conditions it is necessary to regulate the intake of water and salt within certain limits. The attempt on the part of the body to establish an equilibrium is recognized when we recall that the taking in of a large amount of salt causes intense thirst and on the other hand the excessive drinking of water produces a desire for salt. Even sweat has its share of salt, that of humans (who normally perspire nearly a quart a day) containing 3/10 of 1 per cent. in the female, and nearly 4/10 of 1 per cent. in the male!

Then there is our mite of iodine from the sea. And what a mite it is. Yet without it we are hopeless idiots unable to regulate our body fires, and everything we do we either overdo or underdo, depending upon the functioning of the iodine gland that keeps us in touch with the sea.

Our Mite of Iodine

This gland, by the way, is present in all vertebrate animals, beginning low down in the scale, with the eels and lampreys and complicating its structure and increasing its size as the evolutionary scale increases. In fish, the thyroid occurs as small scrubby patches little larger than pin-heads and scattered along the important blood vessels. Then in the reptiles it is a little larger and more compact, and still more prominent among the birds and the mammalia. But it is in the primates and in man that it attains to greatest size. The farther we are from our early home in the sea the larger the thyroid gland—and since evolution never stops its course more than likely man's appearance may eventually change, because of thyroid growth, so that he will no longer be the good-looking creature he now thinks he is—but he will have evolved into a pop-eyed, fat-headed, chinless creature—the space between his chin and his collar button having been taken over by his constantly enlarging iodine plant.

But that is too far off to worry about. Much can happen in a million years. Listen. The high tide of this element in the blood is about one grain of iodine to ten million grains of blood, or less than a hundredth of a grain to the entire circulation. The reservoir of iodine in the body, namely the thyroid gland, only holds a third of a grain (about 25 milligrams) and in order to keep this reservoir full one only has to consume per day, in his food or drink, less than a thousandth of a grain of iodine. No wonder some folks believe in homeopathy. It seems the Great Designer did!

Fry-day

I do not know the canons of the Church of Rome, nor its history, well enough to identify the origin of the custom of sea-food for Friday. In any event it is a good custom, for though Friday euphoniously admits of a fry—fried fish will furnish our weekly requirements of iodine far better than anything else we might fry, or try. And so, much like the Mosaic indictment of pork whereby our Jewish friends are denied the blessed privilege of a ripe red ham unless they call it pickled salmon—Friday for fish may have had a hygienic sanitary origin.

Moses may have fooled Pharaoh with a lot of phony tricks, but he led his people with real thinking.

And while we are speaking of these primitive, intuitive health precautions—listen—while London was yet a muddy fen and Rome a rambling village—China had a mind of her own, and a culture of her own as well. When the civilizations of Athens and Rome were still in knee pants—Cathay had spun her cycles. Four thousand years ago the Chinese had guessed that goiter was a dietary deficiency disease—that it mostly attacked people who shunned the sea and found their safety far inland—that it yielded to treatment with sea medicaments—salt of the sea—sponge from the sea—sea weeds and coral.

Yes, indeed, the art of the ancients was in knowing how—not why.

Burnt sponge was used in medicine for centuries, only to be displaced in modern times by iodine and its compounds. Indeed the first Pharmacopoeia of the United States, published in Boston in 1820, gave it a place though it was deleted in the next revision. So too was a variety of burnt sea weed included. To-day burnt sponge and bladder-wrack are still used by the eclectic physicians, who believe that these natural products, in contradistinction to iodine or its definite artificial compounds, contain a structural "something" that must be very different from pure iodine. And they may be correct in their assumption.

A strange fact regarding sponge is its property while alive of abstracting iodine from sea water. In some tropical species of sponge the iodine content of sponge ash may run as high as 8 to 14 per cent., while sea-weed ash from which some commercial iodine is obtained rarely exceeds 1.5 per cent. Since it is assumed that all the iodine in sponge comes from sea water and sea organisms, it has been calculated that one pound of sponge contains the total iodine content of twenty thousand tons of sea water. Rather a remarkable figure.

Most sea organisms, plants and animals too are rich in iodine. Even the humble oyster, whether brought up in well-aired beds or not, contains his share of iodine.

Sea water contains about 1/300th of a grain of iodine to each gallon (0.05 mgm per liter). It is of interest in passing to note that the Great Salt Lake of Utah contains but a little more iodine (about 1/200th grain to the gallon), whereas it contains five times as much salt.

Of interest, too, is the fact that we have enough iodine in the sea to last our children for a long, long time. Practically all the iodine on this planet is in the sea and another dabbler in useless arithmetic has figured that it amounts to a few pounds short of sixty billion metric tons which antiseptically and biologically leaves us nothing to worry about.

South Carolina has capitalized the alleged heavy iodine content of her vegetables by ridiculously adding the word *Iodine* to her automobile license plates, and by circulating a silly slogan—

A potato a day
Keeps goiter away.

Which shows how the low surface tension of ignorance can make even the so-called authorities run away from sound sense. The "Carolina Moon" *will out*.

Yet much has been constructively done to awaken the world to the realization of the fact that iodine deficiency in food is the commonest cause of goiter and other diseases. The resulting world-wide movement to insure the presence of sufficient iodine in the diet to prevent these dreaded diseases is one of the greatest prevention measures undertaken by man in the interest of good health. Yet the wholesale methods used have not been without danger, for there are types of gland affections which are radically aggravated by iodine medication, and are only amenable to surgical care.

Had we more space at our command we might have dwelt more fully upon these prophylactic measures—such for instance as the now tabooed charging of

drinking water with iodides, or the general use of iodized salt. Iodized salt, containing from 0.02 to 0.025 per cent. of iodine in the form of iodides, is now available in the stores. But we repeat that with community medication of this kind, it must not be overlooked that harm can come from feeding iodine to individuals who already have enough or too much, just for the sake of catching those who have too little. It is a matter always of individual treatment. Nor must we overlook the danger of inducing in the individual through over-dosage that uncomfortable chemical disease, iodism. Indeed it is not always a matter of over-dosage, for to iodine as well as to almost everything, there are persons who display idiosyncrasy.

Yet in spite of our alleged progress in the etiology and treatment of goiter and other thyroid disorders, warning comes recently (April, 1935) from Dr. Arnold Jackson, of Madison, Wis., that thyroid diseases are decidedly on the increase. As many as four fifths of the girls and one fifth of the boys living in the great goiter belt, which extends from Boston to Seattle, are afflicted with goiter, Dr. Jackson found in a nation-wide survey of the problem. Cretinism, resulting from this type of goiter, is more prevalent in the United States to-day than at any time in the nation's history.

But we are digressing too far from our text—and postponing too long our "Amen."

So—abruptly—come we to the close of our sea sojourn—stopping at the harbor of "just enough." There was much more of the sea to be seen—and more to contemplate—but like every other voyage, even a verbal voyage must have its sensible end.

One hope, however, finds expression here—and it is that my readers, touching ground again, will find their land-legs not unsteady, nor their minds still too much at sea—for all the odd things we have said.

And I end as I began—with a swinging song that carries the cry of the primal cell—the lilting, liquid, lullaby urge of every living particle that constitutes our bodies—the death-bed dirge of every animate entity.

I must go down to the seas again, for the call of the running tide
Is a wild call, and a clear call that may not be denied.
And all I ask is a windy day, with the white cloud flying,
And the flung spray—and the blown spray—and the sea-gulls crying.

—*Masefield.*

PREHISTORIC TRADE IN THE SOUTHWEST

By Professor HAROLD SELLERS COLTON

DIRECTOR OF MUSEUM OF NORTHERN ARIZONA

THE movement of goods from one part of the country to another is an intriguing subject. Economics, religion and esthetics furnished the driving force and transportation a romantic intermediary. As trade plays such a lively part of our own lives we may wonder about trade in the pre-Columbian past. Notwithstanding the fact that study of prehistoric trade demands the most highly technical services of any branch of archeology, yet the archeologist has a considerable fund of information at hand.

However, whenever an archeologist takes up the subject of trade he shortly runs into problems that he himself is unable to solve with archeological techniques, so he must call on some man or woman trained in some other service if he wishes his problem solved. He may need the services of a petrographer, a chemist, a botanist, a zoologist or some other specialist. The progress that has been made in the study of prehistoric trade in the Southwest furnishes a splendid example of cooperation in science.

As the term trade has many meanings, among which the exchange of goods is the most common, perhaps commerce would be a better word than trade, because we can not always prove an exchange of goods. I am, therefore, going to show you some aspects of prehistoric commerce as archeological excavation has outlined it in Arizona, which may or may not include an exchange of goods.

To give you some idea of Indian commerce I will tell you about two historic examples; examples, however, that seem to have their roots in deep antiquity. Until 1880 and the coming of the Atlantic and Pacific Railway, the Indians of northern Arizona were little affected by white men. Although the Apache had dislocated more or less all commerce to the south, yet the east-west commerce across northern Arizona was still much as it had been in prehistoric times and men living to-day have had a part in it.

We will first consider a well-known old trade route which ran from the Pacific Coast in the Los Angeles area to the Rio Grande. This trail in general followed the route of the Santa Fe Railroad or U. S. Highway 66. From the Cajon Pass to the Hopi Towns the trail went north of the railroad because the water holes were closer together. It passed through the country of the Mojave, Walapai and Havasupai Indians. From the Hopi country it turned southeast to Zuni and then east to the Rio Grande near Isleta. Over this thousand miles of trail, shell from the coast passed to points on the plateau and along the route other objects passed east and west. Spier[1] reported how the Walapai Indians killed deer or mountain sheep and traded the hides to the Havasupai, for woven goods procured from the Hopi. The Havasupai in their homes tanned the hide and traded it to the Hopi for woven goods and pottery. The Hopi manufactured the buckskin into white boots for their women or traded the hides or boots to the Zuni or Rio Grande pueblos, receiving in return turquoise from Santo Domingo, Mexican indigo from Isleta and buffalo skins from the plains.

This old trail was in active use in 1776, for Father Garces[2] saw abalone shells from the Pacific Coast, textiles from the Hopi and textiles from the

[1] Leslie Spier, *Anthrop. Papers*, Am. Mus. Nat. Hist., Vol. 39, part 3, 1928, pp. 244–245.

[2] Elliott Coues, "Trail of a Spanish Pioneer," pp. 325–326, New York, 1900.

Spanish at Santa Fe at different points in Western Arizona. He describes a Hopi man and wife on a trading expedition to the Mojave.

This famous old trail is now abandoned, but the trade between these Indian tribes is still quite active, passing over U. S. Highway 66. I have sometimes picked up hitch-hiking Indian traders on the roads. When several years ago, a bus was struck on a grade crossing by a train at Isleta, New Mexico, among the dead was a Santo Domingo man returning from a trading trip to the Hopi. This event was impressed on my mind because he had spent the night before with the Hopis at the Museum at Flagstaff. Indian commerce is not dead.

Probably the most interesting story of aboriginal trade is that of curious red paint, a particularly greasy red ochre, procured by the Havasupai Indians from a cave in the Tonto formation in the Grand Canyon near the mouth of Havasu Creek. This paint is in great demand by the Hopi and other Indians for a face and body paint. It is red, yet has a metallic sheen. The Hopi Indians purchase the paint from the Havasupai for \$5.00 a pound, write up the price, and peddle it to other Indians, even as far as the Rio Grande, for 25c a teaspoon. This red paint is considered by the Indians of the Southwest a very superior cosmetic.

This trade in red paint is of long standing and formed the basis of an inquiry called by the Spanish Viceroy of New Spain near El Paso in the year 1691. After the Spanish were expelled from New Mexico by the pueblos who revolted in 1680, the Count of Galve, the Viceroy, wrote a letter to Don Diego De Vargas, then the Governor of New Mexico, who headed a government in exile at El Paso. From Espinosa's[3] translation of this letter I quote the following extracts. The Viceroy wrote:

From the accounts of persons who have lived there I am told that in the revolted province of New Mexico is located the province of Moqui and that a distance of twelve leagues from there toward the big river (he means the Colorado River) there is a range of mountains one of the most prominent in those parts, in which is found a metallic substance or earth containing vermillion. This is used by the Indians to paint themselves with, and by all the people especially the Spanish women to preserve the complexion. . . .

It is said that the metal is heavier than lead and so liquid and greasy that it goes through the leather pack saddles and pack cloths of the pack animals on which it is carried and that when carried leaves red stains, with the result that it has commonly been held to be quicksilver.

As mercury ore was badly needed in Mexico in the refining of silver and at that time all was imported from Peru or Spain, the finding of mercury ore in New Mexico would be of great economic importance. Therefore the Viceroy ordered Governor De Vargas to interrogate witnesses under oath as to what they knew about it. So an investigation was held at El Paso to which De Vargas called military men, padres and others. During the investigation the witnesses told how this red ore was gathered from a cave west of Oraibi. Although not one of the Spaniards had seen the cave they mentioned friends who had visited it. They confirmed the data in the Viceroy's letter how Hopi traded it to Santa Fe where the Spanish ladies preferred it to all other kinds of rouge. On the strength of this testimony De Vargas was ordered to make an expedition into New Mexico. This he did and reached the Hopi town of Oraibi, where he purchased a burro load of the ore. He sent it on to Mexico City, where it was assayed. It proved not to be an ore of mercury. This little incident shows how old the commerce in Havasupai red ochre is. We have documentary evidence that it was an article of trade before 1680 as it is an article of trade to-day.

I could tell of other modern Indian trade such as funereal and ceremonial garments made by the Hopi and traded

[3] J. M. Espinosa, *New Mexico Hist. Rev.*, 9: 2, 113, April, 1934.

to the Rio Grande, but the cases I have reported will serve as examples as to how Indian trade takes place at the present time and it was probably not very different in the past.

The aim of an archeologist is to outline the history of a people by uncovering the mess that they made when they were alive, their houses, burial ground and their city dumps. By excavation a relative chronology can be built up by stratigraphy and an absolute chronology established by studying the annual rings in timber or charcoal from the ruins. After he straightens out the time sequence he tries to distinguish different cultures in time and space and from these data reconstruct their history.

The archeologist must define the characteristics of the people whose history he is reconstructing. He must study their material culture, that is the objects manufactured by the people, houses, stone implements, pottery and the thousand and one objects used in their daily life. He wants to know the physical build of the people so that he can know to which race they belong. Thus he studies the skeletons from the burial grounds. To know if different tribes or races are contemporary he tries to recognize objects of commerce. To determine the routes of trade he delves in the geography of the country. To recognize centers of population he makes an archeological survey.

In the past many archeologists dug for the purpose of placing objects of art on museum shelves. This aspect of archeology is rather going out of style, but it is still the easiest way to attract money for archeological investigation. Now we want to reconstruct the history and life of a people as far as it is possible to do so, and art is but one aspect.

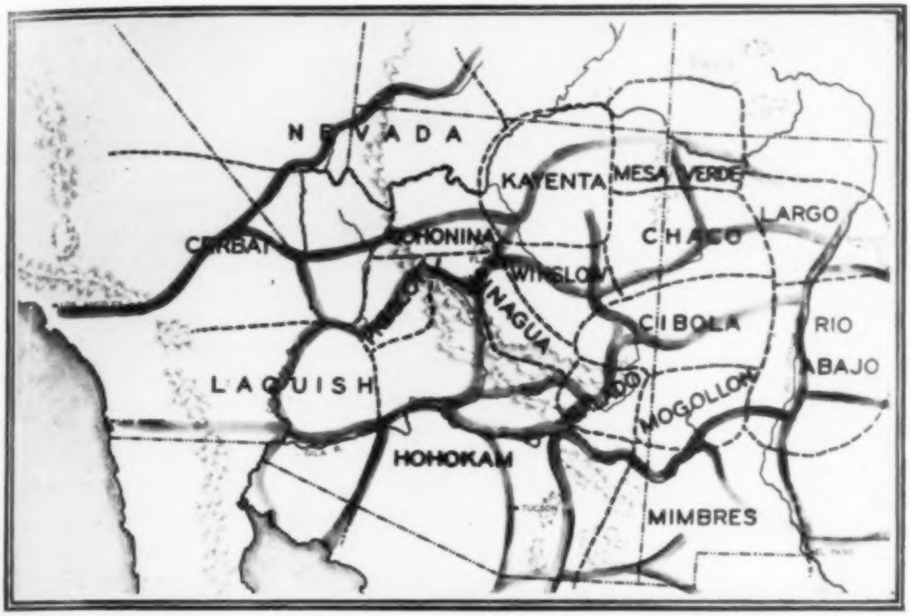
The study of ancient Indian commerce is the most highly technical branch of archeology and requires the services of technically trained investigators in many fields of science. Archeologists themselves can only formulate the problem because all the material has to be accurately identified so that the source can be determined.

Of all the aspects of archeology, a study of Indian objects of trade costs most in dollars and is the most difficult to finance. We must thank those investigators and their institutions for making identifications without charge to the archeologists. If this generous aid were not forthcoming we would know little of aboriginal Indian commerce.

Marine shells form one of the best sources for the study of Indian trade, because marine shells were used for ornaments and are found in prehistoric sites all over Arizona and New Mexico. To determine if they came from the Gulf of Mexico, Gulf of California or the Pacific Coast of California means that they must be identified by a trained malacologist or conchologist, a student of the Mollusca. Boekelmann in New Orleans and Hill at Los Angeles have been rendering this service to archeologists but curators of other east and west coast museums have been giving their valuable time as well.

To determine the source of stone objects and the stone used in pottery for temper requires the services of a petrologist who makes thin sections of the pottery and studies the sections with polarized light, and measures the crystal faces of the minerals. It takes a highly trained man or woman to do this and interpret the results. Dr. Anna Shepard, of the Carnegie Institution, has been preeminent in this field.

To determine the source of some material we must call in the chemist, using ordinary methods of analysis or a spectroscope. An ornithologist, from the bones of birds, must recognize the species, and, from mammal bones, a mammalogist must identify mammals. An ethnobotanist must be called in to determine the source of fibers used in basketry and remains of food plants uncovered from



MAP OF THE SOUTHWESTERN PART OF THE UNITED STATES

SHOWING THE LOCATION OF THE DIFFERENT INDIAN TRIBES CALLED "BRANCHES" AT ABOUT 1100 A.D. THE NAMES OF SOME OF THESE BRANCHES HAVE BEEN SUGGESTED BY GLADWIN, OTHERS BY MERA, ROGERS AND THE AUTHOR. THE MAP ALSO SHOWS THE VARIOUS TRADE ROUTES, PARTLY AFTER BRAND.

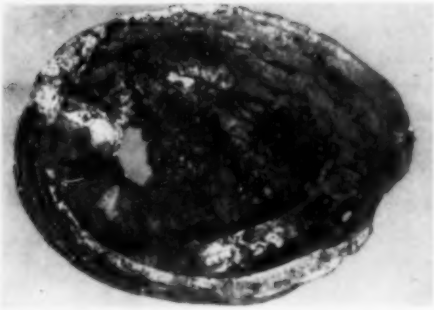
the ruins. He can tell the archeologist from what area the plant products were gathered or grown. So you can see that many sciences must be called upon in the study of prehistoric commerce.

Prehistoric commerce may have three phases: Manufactured goods, such as textiles or pottery, may be made in one area and consumed in another. Natural products, such as shells, pipestone, turquoise or salt, may be gathered by the people of one area and consumed by the people of another area. At a red argillite quarry near Del Rio, Arizona, there is a Pueblo ruin which is covered with fragments of the red rock. Evidently the local people quarried the rock and traded it to other places. On the other hand, a consumer might travel a long distance and gather the shell, the salt or the turquoise himself and carry it home. Rogers[4] believes, for example, that the pueblo people may have gone to the Mojave Sink in California to mine turquoise. Expeditions of this sort do not constitute trade in the true sense, for here there was no exchange of goods, so, as the archeologist can not distinguish between them, as I said before, we will call any objects produced in one area and consumed in another commerce or trade.

In prehistoric Indian commerce, we must remember that there were no beasts of burden. Everything had to be carried on the backs of men and only goods of little bulk and high value such as dyes, pigments, fine textiles, ornaments and small attractive pottery vessels constituted this commerce. Necessaries which had bulk, although desired, could not be transported. This was true also of the old world, where overland caravans carried objects of high worth and little bulk, such as silk and spices.

We know nothing about the organiza-

[4] M. R. Harrington and M. J. Rogers, *San Diego Mus. Arch.*, 1: 1, February, 1929.



A HALIOTIS SHELL

THESE SHELLS CAME FROM THE PACIFIC COAST. THE HOLES ARE PLUGGED WITH ASPHALT TO MAKE A BOWL. THIS SPECIMEN WAS EXCAVATED FROM THE RIDGE RUIN NEAR FLAGSTAFF, ARIZONA.

tion of prehistoric Indian trade. Were objects traded from village to village or were trading expeditions organized? We do know, however, that the Southwestern Indians trade as individuals and at times have organized armed bands for the purpose of trade with distant centers. The Aztecs organized such expeditions; the Pima, Hopi and other Southwestern tribes sent out trading parties to visit distant tribes. Bands of Santo Domingo traders often visit the Hopi and Navajo. Hopi traders visit the Zuni or the Rio Grande. We can reason by analogy that the ancient people did the same.

These trading parties were different from the caravans of the old world, where there was a division of labor among the members of the party. In the old world we find a group of traders, with soldiers, camel boys and camp followers. As far as we know in the Southwest every man was for himself, he was the trader, pack animal, and soldier. There was little or no division of labor.

The prehistoric Indians of Arizona had no medium of exchange such as wampum. Their ornaments, shell and turquoise probably served this purpose just as the pueblo Indians and the Navajo use silver jewelry at the present day.

To understand the flow of prehistoric Indian commerce we must recognize and locate on the map prehistoric Indian tribes. These Indian tribes are separated from one another by such traits as one can find in excavation—burial customs, architecture, pottery and other evidences of material culture. As we know nothing of the language and social organization of prehistoric Indian tribes, it is better to follow Gladwin[5] and call prehistoric social units branches. In the Southwest about the year 1100 of our era archeologists recognize something over 21 branches, each one of which we might call a tribe. Between these branches are evidences of commerce of some volume.

In this paper I will frequently mention some prehistoric site in New Mexico and Arizona, so it will be well if I say something of the branch in which they are located. In southern Arizona in our Middle Ages a culture flourished which we call the Hohokam. A site most thoroughly excavated and reported upon by Gila Pueblo is Snaketown.[6]

A culture that flourished south of the San Francisco Peaks in central Arizona we call the Sinagua. Tuzigoot in the Verde Valley, Wupatki, Elden, Turkey Hill, Ridge Ruin belong to this culture. At Winona, 17 miles east of Flagstaff, lies a site which represents a Hohokam migration into north-central Arizona. In northwestern Arizona, the Kayenta branch included such important sites as Batatakin, Inscription House and Kiet Siel. In southwestern Colorado the Mesa Verde Branch includes the important cliff pueblos of the Mesa Verde National Park. The Chaco Branch occupied northwestern New Mexico. Pueblo Bonito and Chettro Ketl are important sites in this culture. Across the Rio Grande, southwest of Santa Fe in New Mexico, the important pueblo of Pecos was excavated by Kidder. The trade

5 W. and H. S. Gladwin, Medallion Papers, No. 15, 1934.

6 H. S. Gladwin, E. W. Haury, E. B. Sayles and N. Gladwin, Medallion Papers No. 25, Vol. 1, 1937.

material found in these sites and many others form the substance of this paper.

Fragments of ornaments made from marine shells are found in most sites in the Southwest. All these shells were gathered from the ocean, and so they all represent commerce. Dr. Donald Brand[7] has made an especial study of prehistoric Indian commerce in shell, tracing them from the Gulf of Mexico, Gulf of California and the Pacific Coast to different parts of Arizona, New Mexico, Colorado and Utah. Dr. Brand based his conclusions on the study of reports of archeological excavations. He found that in most reports of archeological excavations the identification of shells was performed in too sketchy a manner to be of much use, but in a number of recent works and a few of the older reports the shells were identified by recognized malacologists. Dr. Brand reported 38 species from the Gulf of California, 9 species from the Pacific coast, 10 species that might have been found either in the Gulf of California or the Pacific coast, and 9 from the Gulf of Mexico; all the latter are found east of the Continental Divide in New Mexico except a couple of doubtful identifications from the Salt River Valley.

Dr. Brand did not have access to the recent work of the Museum of Northern Arizona in the Flagstaff area. On having our shells from the Hopi Country and Flagstaff identified by Boekelmann and by Hill we found we had added seven species to Dr. Brand's list of 66 traded marine shells. Three are found only in the Gulf of California, three are found only on the Pacific Coast, and one is found on both coasts.[8]

[7] Donald D. Brand, Year Book of Pacific Coast Geographers, Vol. 4, p. 3, 1938.

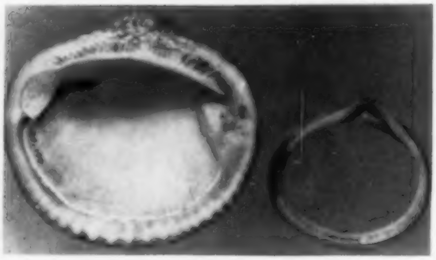
[8] The following shells, excavated near Flagstaff, are not mentioned in Brand, 1938. From Gulf of California: *Nassarius versicolor, Turritella goniostoma* and *Glycimeris tesselata.* From Pacific Coast: *Haliotis corrugata.* From Gulf of California or Pacific Coast: *Panope generosa solida, Dentalium neohexigonium* and *Dentalium semipolitium.*

From the Pacific Coast the most important shell carried into Arizona and New Mexico was the abalone shell called *Haliotis.* This shell is not found in the Gulf of California, so it forms the best indicator for Pacific Coast trade. It was used for dishes when the holes were plugged with asphalt and small iridescent fragments of abalone mother of pearl were carved and used for ornaments.

The Indians of the coast made fish hooks of abalone shell. First they cut an oval piece out of the center of the shell. Then with a piece of flint they bored a small hole off center. This hole they

FISH HOOKS OF HALIOTIS SHELLS

THIS MANUFACTURE WAS AN IMPORTANT INDUSTRY OF THE PACIFIC COAST INDIANS. (a) HALIOTIS SHELL WITH BLANK CUT OUT WITH THE CHERT FLAKE (g). (b) BLANK CUT FROM THE SHELL. (c) AND (d) BLANKS DRILLED AND REAMED WITH IMPLEMENT (f). (e) A FINISHED FISH HOOK. (h) A PAIR OF EARRINGS FROM THE RIDGE RUIN NEAR FLAGSTAFF, ARIZONA, WHICH ARE OBVIOUSLY MADE OF HALIOTIS SHELL FISH HOOK BLANKS WHICH HAD BEEN TRADED INTO NORTHERN ARIZONA. THE PHOTOGRAPHS OF THE STAGES IN MANUFACTURE WERE FURNISHED THROUGH THE COURTESY OF ARTHUR WOODWARD OF THE LOS ANGELES MUSEUM.



GLYCIMERIS SHELL AND RING

GLYCIMERIS SHELL, LEFT, WHICH IS ONLY FOUND IN THE GULF OF CALIFORNIA. RING, RIGHT, MADE FROM A GLYCIMERIS SHELL BUT FOUND AT WUPATKI, A PREHISTORIC RUIN NEAR FLAGSTAFF.

enlarged by grinding with a conical stone. When a hook was needed, the Indian took a blank and cut away the shell, making a hook. When Arthur Woodward of the Los Angeles Museum saw some ornaments, a pair of earrings that we found in the Ridge Ruin, he pointed out to us that they were made out of West Coast fish-hook blanks. It is not in many parts of the world that earrings are made out of fish hooks.

Glycimeris shells, which are bivalves, were gathered on the beaches of the Gulf of California and the centers cut out before transportation. Woodward[9] has found sites of this industry in Sonora, where the circular discards cut from the shell were left on shell heaps. In that way the trader had less weight to carry when he set out on his long tramp to the Hohokam Villages in the Gila Basin.

Small conus shells had the spire ground off and were used as tinklers. The present-day Indians of the plateau make similarly shaped tinklers of tin. Olivella and nassarius were made into beads as well as pelecypod fragments.

Most of the shells found about Flagstaff, at Snaketown and Tuzigoot were derived from the Gulf of California. Yet others came from the Pacific Coast. It is evident, as Haury[10] suggests, that the Hohokam area must have been the commercial distribution center for much of this trade in the Southwest.

Stone such as diorite for axes, soapstone, red argillite, and turquoise for ornaments and malachite, cinnabar, and hematite for paint were widely traded, but much exploration in rough difficult country is needed before the exact sources of all the materials are located.

In the excavation of a pit house in Picture Canyon, 6 miles east of Flagstaff, the author once unearthed a cache of six unused three-quarter grooved axes of diorite, which were buried in the debris on the floor of an abandoned pit house, probably by a trader who never returned to recover them. This diorite must have come from Southern Arizona and possibly even from Sonora, where Woodward[11] reported green diorite implements in abundance in the Altar district.

At Ridge Ruin were found some small soapstone (steatite) ornaments. Steatite is not found in the plateau but is found in the mountains of the Gila River Valley, as reported by Haury.[12]

One sometimes finds large buttons of lignite in the excavations. We would look for the source of this material in the various Mesozoic coal measures which cover certain areas of the plateau from Kayenta and Oraibi to Gallup or near Santa Fe. When found at Flagstaff, it is certainly an object of trade whatever the exact source may be.

At Tuzigoot, Ridge Ruin and at other sites small ornaments such as nose plugs, lip plugs and the small images of animals and birds have been found made of red argillite.

Two years ago we located a prehistoric quarry of red argillite in the Mazatzal Quartzite, a Pre-Cambrian rock, near Del Rio in Yavapai County, Arizona. The ornaments from the sites and the material from the quarry have been analyzed by the spectroscope by David E. Howell[13]

[9] Arthur Woodward, *Am. Antiquity*, 2: 2, 117, October, 1936.

[10] E. W. Haury, Medallion Papers No. 25, 1937.

[11] Arthur Woodward, *op. cit.*, p. 120, 1936.

[12] E. W. Haury, *op. cit.*, p. 129, 130, 1937.

[13] David Howell, Ms.

and have been found to be identical. Near the quarry lies a medium-sized pueblo, among the ruins of which are found thousands of fragments of argillite. This material was probably traded into the Verde and from there over the Southwest.

Copper bells made by the *cire perdu* (lost wax) method have been found in excavating in New Mexico and Arizona. As was pointed out by Gladwin, the casting of these bells in copper by the *cire perdu* method by primitive people involves a high degree of technical knowledge and skill. Forty of these bells have been chemically analyzed by spectroscopic methods by William C. Root, of Bowdoin College, Maine. He reported that the copper bells from the Southwest were not made of copper from the plateau of Mexico or from Lake Superior Region, and Haury suggests that they were either made in the Hohokam area of southern Arizona or in northern Mexico.[14] Four of the ten bells found in the Flagstaff area have been analyzed by Dr. Root. He found the composition similar to 40 other bells from Arizona and New Mexico. As they could not have been made in the Flagstaff area they represent trade from southern Arizona up the Verde trail.

Animal remains in the ruins are quite common and are important to record with great accuracy not only because they give clues to the environment of the people but also because they show trade relations. Parrot remains were not reported from Snaketown, but a number have been found at Wupatki near Flagstaff, at Tuzigoot, and Pepper (1920, p. 194) found 14 in a room in Pueblo Bonito. These parrots from the Flagstaff area have been identified by Dr. Alexander Wetmore as *Ara militaris mexicana*, Mexican green macaw, and *Ara macao*, the red, blue and yellow macaw. The habitat of the green macaw lies in tropical Mexico and now extends north as far as the Yaqui River in Sonora. The habitat of the red, blue and yellow macaw lies in South America, but its range now extends along the east coast of Mexico as far north as Tampico. Fewkes[15] described a desiccated macaw from a burial at Wupatki near Flagstaff, with the feathers still on it, and the Museum of Northern Arizona discovered the remains of several other macaws that had been carefully interred. It seems evident that the birds were valuable and were traded up to northern Arizona from Mexico alive. Even if the ranges of these birds extended farther north 700 years ago than now, this trade represents fairly rapid transportation over a very long route.

From the excavation of the Ridge Ruin were recovered a number of objects, mostly turquoise mosaics mounted on some sort of a plastic. Among the objects was a wooden wand with a plastic head inlaid with turquoise mosaic. A glycimeris shell bracelet had a sheet of plastic attached by a lug protruding through a hole in the shell and on this sheet a turquoise mosaic was set. This same plastic was found in balls on certain sticks and in granular form. This

MACAW SKULL

SKULL OF THE RED, BLUE AND YELLOW MACAW, ARA MACAO, A PARROT FOUND IN THE TROPICAL PART OF THE EAST COAST OF MEXICO. THE SKULL WAS FOUND AT WUPATKI, NEAR FLAGSTAFF.

14 W. C. Root, Medallion Papers, No. 25, 1937, p. 276.

15 J. W. Fewkes, "Two Summers' Work in Pueblo Ruins." BAE 22nd An. Rept. 1904, Pt. 1, p. 50.

material was sent to Dr. Volney Jones, of the University of Michigan, for identification, who reported it as lac, the secretion of certain scale insects that inhabit the creosote bush (*Larrea*) and some other desert plants. At present the lac insect is quite scarce in southern Arizona but is found in some abundance on the creosote bushes in western Arizona near Kingman. Lac is an alcohol soluble resin identical to shellac from India, which is the basis of our shellac and sealing wax.

Lac was probably prepared by scraping insects off the branches of creosote bushes. We found in the ruin a quantity of the untreated lac secretions just as they were scraped off the bush. This crude lac was probably melted and stirred with sticks, for we found sticks with balls of lac in the excavation. It was then molded into thin sheets of different shapes which were decorated by imbedding turquoise or other fragments in the surface. When hot the lac can be molded in any form and is a convenient plastic for the manufacturing of many small objects, on which turquoise fragments can be imbedded. The Indians of the Colorado basin at the present time use lac for many purposes, to waterproof their baskets, patch cracks in their water jars, and for balls used in games. Now that lac has been recognized from a prehistoric site it will probably be discovered in other collections of material from the Southwest.

The presence of lac in some abundance in a burial at the Ridge Ruin, a site near Flagstaff, indicates trade probably from the Colorado Valley. Although lac is found in the Gila-Salt area and in the Grand Canyon, it is less abundant than in the area around Kingman, Arizona, and so harder to collect.

My own interest in prehistoric trade lies in the field of pottery, because pottery remains are so well preserved in prehistoric sites and are so abundant that the volume of trade can be indicated. Copper bells, parrot remains, argillite and turquoise ornaments are rather rare, so rare that their contribution to commerce was rather small unless the ornaments represent a medium of exchange. However, the volume of pottery traded was enormous.

To distinguish traded pottery from the indigenous pottery requires a study of the pottery of the whole Southwest. This means that we must have accurate descriptions of types, covering methods of manufacture, structure of the core, kind of temper, surface treatment and styles of decoration. As almost four hundred pottery types are recognized in the Southwest, no one can carry the details of all these in his head, therefore, whether we like it or not, some method of classification is necessary. Then again some archeologists have been very careless in the identification of the types that they have described, renaming types that have already been named, or describing types so loosely that comparisons are impossible, so many types bear several names. A number of types have as many as five names. So my efforts first have been to recognize synonyms, second to classify the types into larger groups called wares, and third to determine the region in which each type was manufactured. I have begun, so to speak, at home in the San Francisco Mountains and have slowly spread out into other areas. I feel I have only made a beginning, but other workers in the Southwest have cooperated, so in a few years our foundation will be much more secure than it is at present.

I wish to particularly urge archeologists not only to have their types carefully identified, but to save large samples of each type from a site so that they can be re-examined a few years later as new technical methods are made available. It is the custom of archeologists, after a study has been completed, to scrap all sherds, so it is forever impossible to determine the source of trade pottery by future methods of analysis.

For the determination of the home

town of a piece of pottery we have to examine a broken surface. Museums will not let us break pieces out of their treasured whole vessels, so we must study sherds. The best determiner of an indigenous type—by that we mean pottery made on or near a site—is the utility vessel, a storage or cook pot. These are usually large and hard to transport, so the fragments are apt to be found close to the place of manufacture, and, if transported as they sometimes were, their fragments form but a small proportion of the sherds in the new area.

Most prehistoric Indians made, besides their large storage and cooking pots, small bowls and jars in which food was served. On these the potter gave loving care and they show the finest results of the arts and crafts of a people, but these small bowls were so widely traded that it is difficult sometimes to locate their home tribe. As these vessels were used in serving food, we will call them "service types."

It is most important to determine the place of origin of attractive "service types" which were small in size and widely traded, and it is not always an easy thing to do this. A criterion often used by archeologists is local abundance, but this is not a safe guide, particularly if the vessels were found in burials because valuable exotic objects were selected for burial offerings. A type called Jeddito Black-on-yellow is a service type made from 1300 to 1500 A.D. of Hopi clay in the Hopi country. The clay is similar to the clay used in the manufacture of storage and cooking vessels from the Hopi country, except that little or no sand was used for the temper. Jeddito Black-on-yellow was so abundant in burials in certain sites in the Verde Valley and Tonto Basin that some archeologists have considered a Hopi migration into those areas in the 1300's. However, as the corresponding cooking and storage vessels were not found with them I suspect trade, particularly as chemists have shown that the clay in those vessels was not local but was similar to Hopi clay.

Between 700 to 1300 A.D. the women of the Kayenta Branch in northern Arizona made small bowls of black-on-white pottery and corrugated cook pots. Fragments of their black-on-white bowls are found in almost every excavated site in the Salt River Valley and whole pieces in some. As the style of design changed over a period of years and these designs have been dated by the tree ring method thus have the Salt River Valley Ruins been dated. Excavations at Chaco Canyon, New Mexico, have uncovered Kayenta pottery. It has been found as far west as the Mojave Desert. All this points to widespread traffic.

In the San Francisco Mountain black sand area the people made brown storage jars of basalt residual clay with crushed volcanic tuff temper, also small bowls of red with a black burnished interior with basalt sand temper, and red bowls with a black painted design or a polychrome pottery, using volcanic tuff temper. Like the Kayenta pottery these latter attractively painted bowls were widely traded to the major contemporary branches. But the red bowls with a burnished interior called Sunset Red were not so popular, and fragments are rarely found far outside the black sand area.

The red on buff pottery of southern Arizona was little traded to the North, only a fraction of the amount of sherds being found compared out of its environment compared to the amount of northern sherds found in southern sites. Since there was little reciprocal trade in pottery it means that to balance the northern pottery traveling south objects other than pottery were carried north, which was, perhaps, shell and textiles.

I think we can safely say that every Indian tribe in the Southwest that made pottery made a "utility type" for cooking and storage and one or more "ser-

vice types" for serving food. Although the finishing of these two types was often quite different yet they were alike in certain basic techniques of manufacture. Their clays were usually from the same general source, the temper was usually the same except for size, they were fired in the same kind of atmosphere, oxidizing or reducing and constructed by the same methods, coils obliterated by the use of paddle and anvil or coils obliterated by scraping with a piece of sherd or gourd. To settle these finer points the archeologist has often to call in the ceramic technologist, the geologist and the chemist.

Although individuals on foot may traverse Arizona and New Mexico from one point to another from in almost any direction, yet the bulk of the movement would follow certain lines of geographical least resistance. Knowing the centers of population, topography of the country, the source of trade objects, position of water holes and historic Indian trails, we can approximate the principal routes of commerce over the Southwest. Men will go around a rough mountain range, all things being equal; but in a desert region will cross the mountains if they provide water on the way. Across the Mojave desert the Indian trails went from a water hole in one mountain range to a water hole in another mountain range. If you know where to look, water can be found in the mountains every twelve miles or so on his route across the Mojave desert.[16] As the present highway and the railroad avoid the mountains their routes were impossible in prehistoric times.

River valleys with living streams form natural avenues of trade. They supplied water, stopping places in villages and an easy way if the way led in the right direction, so important trade routes must have followed the Gila, Salt, Verde, Santa Cruz, Little Colorado, Puerco and Moenkopi Vallies in Arizona and the Rio Grande, Puerco and San Juan in New Mexico.

(1) Three main routes can be traced from the Pacific Coast. (a) From the region of San Diego up the Gila through the country of the Hohokam to the Rio Grande, as shown by Brand and Haury.[17, 18] (b) From the region of Los Angeles to the Colorado near Needles and on to the plateau following the Little Colorado tributaries and the San Juan into New Mexico. (c) Another route from the Los Angeles area passed north of Boulder Dam to the Virgin Valley sites and other Utah points.

(2) One or more routes led from the Gulf of California to the country of the Hohokam.

(3) From the Hohokam to the Plateau two main routes are indicated. (a) Up the Verde to the Sinagua and Kayenta, and (b) up the Salt to the White Mountains and Cibola Branch. Minor routes led into the most remote areas.

(4) Brand[19] shows three main routes from the Gulf of Mexico into New Mexico, following the rivers Rio Grande, Canadian and Brazos.

So far I have been talking about prehistoric trade during the eleventh to fourteenth century. You may ask, "What of earlier trade?" Gurnsey[20] found in the Basket Maker II caves of northern Arizona whose date might be placed 300–500 A.D., only Pacific coast marine shells, abalone and olivella. In general, shells are relatively rare in the early periods. In Basket Maker III (500–700 A.D.) shells are scarce, but as both glycimeris and abalone are reported we have indications of trade from the Gulf of California as well as the Pacific Coast. In Pueblo I (700–900) in the

[16] Whipple, "Water Holes in Mohavi Desert." 1858. BAE 26th An. Rept. 1908, p. 92.

[17] Brand, *op. cit.*, p. 7.

[18] Haury, *op. cit.*

[19] Brand, *op. cit.*, p. 9.

[20] Guernsey, "Explorations in Northeastern Arizona." Papers of Peabody Museum, Harvard University, Vol. XII, No. 1, p. 68, 117.

San Juan area shell shows trade from both sources. From 800 to 1000 A.D. in the Flagstaff area, shells are scarce, but three species are found that live in the Gulf of California, but none have been reported upon from the Pacific Coast.

In the excavations in southern Arizona in the Grew Site and at Snaketown, pottery is found that was made before 700 A.D. north of the Little Colorado. Plateau types made before 1100 A.D. are found in the desert mountains of northwest Arizona.

In general, we may say that some trade took place in the earliest periods that have been reported upon in Arizona, but that from 1000 A.D. on trade was in a much greater volume than in the earlier periods.

As to mediums of exchange, we have little to say. It is conceivable that the prehistoric people made attractive pottery, especially for exchange, just as the Hopi do to-day. Indeed, the modern Indians use jewelry when they have no cash, but there is no evidence that the Indians of Arizona either in ancient or modern times used shell as the Indians of the East used "wampum" as a medium of exchange with a fixed value. In the Southwest bead necklaces are valued somewhat on the number of beads, but other factors enter into the transaction such as quality and artistic arrangement.

Modern Indians have rates of exchange for goods which fluctuate within narrow limits. Among the Pima, Russell[21] states a gourd equals a basket in trade; a shell necklace, a metate; a basket, a blanket; and a string of blue glass beads, a horse; a string of blue glass four yards long, a bag of paint. Spier[22] reports, among the Havasupai in the period 1840–65, a tray of shelled corn equals a Navajo saddle blanket; the biggest burden basket of shelled corn, a horse; big blanket, a gun; ten buckskins, a race horse. I do not suppose it was more difficult to remember the trade value of their few objects than for us to know the value of our goods in dollars and cents.

You may wonder how far various objects have traveled in prehistoric trade. From the reports of archeological digs we find that pottery travels rarely more than 200 miles, yet other objects can be proved to have traveled much longer distances. Kidder[23] found Gulf of Mexico marine shells at Pecos that must have traveled a distance whose bee line is over 700 miles. He found shells from the Pacific Coast that had traveled almost as far. Some of the parrots, red-blue-yellow macaw, found at Wupatki, must have been carried 1,200 miles, but the longest distance recorded is a vessel found by Pepper[24] at Pueblo Bonito in Chaco Canyon, New Mexico, which might have come from the valley of Mexico 1,300 miles away.

The study of aboriginal trade has just begun. The centers of the manufacture of a few objects have been proved above any reasonable doubt. Although we see dimly some of the broad aspects of aboriginal trade we need the aid of the specialist to help us settle the source of manufacture of many objects. We have made a beginning, but thanks to the gracious cooperation among scientific men, the possibility of further contribution to this study of prehistoric commerce appears to have no limit to its horizon.

[21] Frank Russell, "The Pima Indians."

[22] Leslie Spier, *op. cit.*, p. 245.

[23] A. V. Kidder, "Artifacts of Pecos," p. 183, 1932.

[24] G. H. Pepper, *Anthrop. Papers*, Am. Mus. Nat. Hist., Vol. 27, 1920, p. 208.

A PREFACE TO SOLAR RESEARCH

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THERE are many reasons why study of the sun is one of the most important fields in science. The sun is the nearest star, the only one we can examine in detail. It thus provides a test and check on theories of stellar astrophysics in general. As the center of the solar system, the sun furnishes light, heat and energy to the earth, as well as to the other planets. It is an important factor in controlling the weather. It is the source of the electrification of the ionosphere. Magnetic storms, radio fade-outs and aurorae are clearly connected in some hidden way with sun-spots or, more precisely, with solar variation.

The sun is important for the physicist and physical chemist, as well as for the astronomer. Through the medium of spectroscopic analysis, they gain information about atoms and molecules of the solar atmosphere and learn about the behavior of the elements under conditions of excitation that can not be reproduced in the terrestrial laboratory. Thus they may extend the existing experimental data and check calculations on the behavior and break-down of atoms and molecules. Study of the solar spectrum may well provide new methods for improving the accuracy of spectrochemical analysis.

It is easy to see why numerous observatories have devoted considerable attention to the securing of observations of solar phenomena. The details of the surface layers are of interest in themselves: sun-spots, granulation, faculae, flocculi, chromosphere, prominences and corona. In the United States, observational programs are being carried out chiefly at Mt. Wilson Observatory, at the McMath-Hulbert Observatory of the University of Michigan, and at the newly established Fremont Pass Station of Harvard Observatory, Climax, Colorado. Certain special phases of solar work are being pursued elsewhere, *e.g.*, at the Smithsonian Institution, the McDonald Observatory, and the Yerkes Observatory. The theoretical and interpretive work has been pursued mainly at Mt. Wilson and Harvard.

THE PROBLEM OF INTERPRETATION

Despite the large amount of observational data that has accumulated at various institutions all over the world, progress in the interpretation of solar phenomena has been slow. Our failure to advance has, undoubtedly, been largely due to the inherent complexity of solar phenomena. The nature of the problems is apparent, however, even though their solution seems remote. Can we, at the present point, by taking stock of the existing data and experimental equipment, devise new procedures that will speed the progress of solar science? Are we making full use of the knowledge and techniques of physics and industry?

One of the first points that meets the eye in a preliminary general survey is that theoretical discussion has somehow lagged far behind observation. Experience with other sciences shows clearly that progress is most rapid when theory and observation keep nearly in step, neither outdistancing the other at any time. At least part of the difficulty in the solar problem is that interpretation and theory are often purely physical matters. And few astronomers, unfortunately, are also theoretical physicists, with appropriate knowledge of atomic spectra, statistical mechanics, wave me-

chanics, hydrodynamics, radiation and electromagnetic theory.

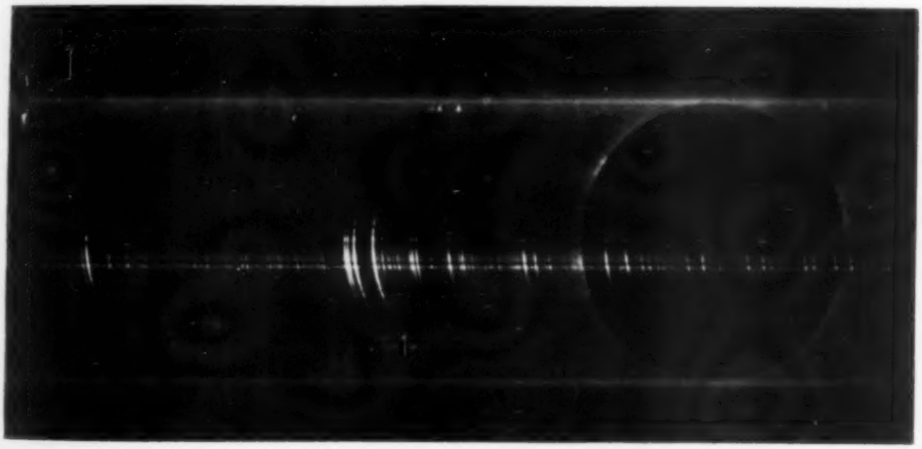
Clearly, all the above fields are significant in the interpretation of solar observations. Likewise, the physicist, who might be capable of contributing, is unfamiliar with both the problems and the observational data. The few theoretical advances that have been made are chiefly of a mathematical nature and, as such, often fail to conform either to physics or to the facts of observation. The resulting theories, in consequence, lack plausibility.

Let us examine a few of the outstanding problems of solar astrophysics, and try to see what new observational data are needed, how they may possibly be secured, and where new techniques or theory may be applied. This outline represents a bare beginning of inquiry into solar problems and omits many important phases, including that of the solar interior.

Sun-Spots Are Vortices

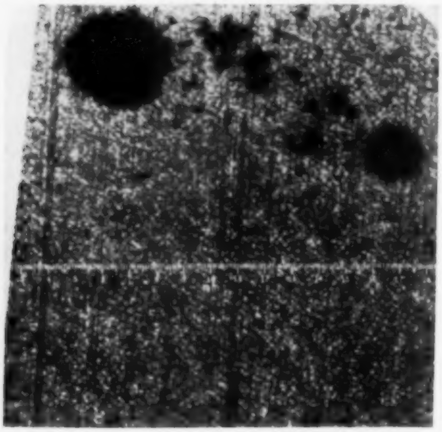
First, consider the question of sun-spots. The direct conclusion from the observational data is that sun-spots are storm areas of a cyclonic nature in the solar atmosphere. They are regions of low pressure, and their darkness is evidently caused by the cooling of the gases expanding into the affected area. The spectra of spots exhibit less excitation than do those of the normal solar surface, in the form of more intense low-temperature lines of neutral metals. Molecular bands, also, are present, showing that the temperature is low enough to permit the formation of elementary chemical compounds. The atomic lines are split and display polarization phenomena characteristic of an intense magnetic field.

It is believed that sun-spots are vortices. In fact, the mere presence of a strong magnetic field is an almost unrefutable argument for the existence of at least an electric vortex or solenoid. But very little is known of the rate of the vortex rotation or of the law that the velocities follow, outward from the vortex center. There seems to be a chance to determine this velocity from observation alone. Most spectroheliograms are



THE FLASH SPECTRUM

A SECTION FROM ONE OF THE FLASH SPECTRA OBTAINED BY THE HARVARD-MASSACHUSETTS INSTITUTE OF TECHNOLOGY ECLIPSE EXPEDITION TO SIBERIA, JUNE 19, 1936. THE COMPLETE CIRCLE NEAR THE RIGHT OF THE PICTURE IS THE CORONAL RING, RECORDED IN THE GREEN LINE OF "CORONIUM." ITS ORIGIN IS STILL UNKNOWN. NOTE THE "CORONAL PROMINENCES." THE BRIGHT LINES AT THE CENTER ARE THOSE OF MAGNESIUM.



Yerkes Observatory.

SOLAR GRANULATION

THE SOLAR DISK, AS SHOWN IN THIS PHOTOGRAPH, IS FAR FROM UNIFORM. THE BRIGHTER AREAS CONSIST OF MYRIADS OF TINY GRANULES, IN A STATE OF RAPID ACTIVITY.

indecisive on this point, either showing no rotation at all or indicating a direction of spin quite different from that required by the magnetic field. A few spectroheliograms that have been made public exhibit the phenomenon of a prominence's apparently being sucked into a vortex. The filaments become more and more curved as they approach the center, which suggests conservation of angular momentum. Measurements of the curvature and the drift of the filaments should give important data concerning the nature of the vortex; at least they will yield information about the effect of the vortex at high chromospheric altitudes. Studies, with motion-picture cameras, of the spots themselves, particularly of the penumbral filaments, should give additional information about sun-spot circulation.

Spots as Giant Electromagnets; a Million Million Amperes

Upon the observational data of this vortex rotation depends the future development of the theories of sun-spot magnetism. The gases that comprise the solar atmosphere are highly ionized, broken up by the action of radiation and high temperature into electrons and ions. It was once thought that mere rotation of the ionized gas would set up a powerful field. But further examination proves that a rotating mass of gas, however highly ionized, will not give a magnetic field if it contains an equal percentage of ions and electrons. For the positive pole produced by rotating charges of one sign is just cancelled by the negative pole formed by the whirling charges of opposite sign. Nor can there be a sufficient excess of protons or electrons to give the field, because a sun-spot so highly charged would break up instantaneously and explosively in the powerful electric field.

It appears that the magnetic field results from a galvanic current produced by actual slipping of charges of one sign with respect to those of the other. The real question is how the enormous currents, which must be of the order of a million million amperes, are set up and maintained. They are probably automatically produced inside any vortex of ionized gas. The exact details of the process are still obscure, but there is hope of solving the problem if only such significant data as the law of vortex rotation can be determined observationally.

The fields probably arise from differences in relative freedom to move of charges of opposite sign. The free negative electrons, extremely light, are easily deflected by collisions with other atoms. Further, they react very rapidly to the existence of even a small magnetic field, moving in small circles, whereas the positive ions move in large ones. A preliminary analysis by Dr. T. E. Sterne and myself is promising in this connection; it shows that we may well expect the electrons to drift relative to the ions. Further analysis, however, is held up by lack of observational data on spot motions as well as by a dearth of knowledge of electron-atom collisions. The latter

information must come from physical studies of the properties of matter.

What is the Shape of a Sun-Spot?

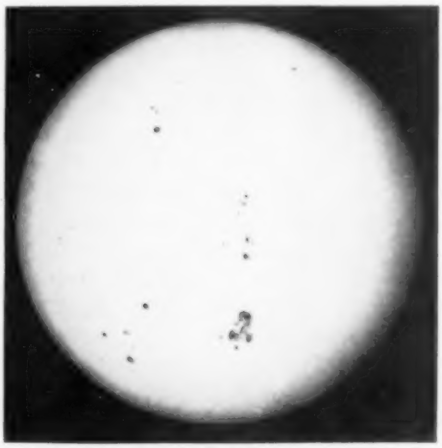
Associated with the vortical motion of sun-spots is the "pumping" action, which draws material up from the heated interior, cools it by expansion, and then allows it to descend. The maintenance of this circulation over long periods of time presents a major problem of sun-spot activity. From theoretical investigations of the circulational features involved, we should be able to decide whether a sun-spot is long compared with its cross-section, like a terrestrial tornado, or whether it is flat, like a whirlpool in a shallow basin. Both concepts have been urged by some astronomers, but the vortex character lends favor to the former view. What, also, is the size of the true vortex, as distinguished from the rotating mass of gas surrounding the spot center, but which is not a true vortex in the strictest meaning of the word? These problems are all allied with the important question of the distribution of temperature and pressure in the vortex. These quantities are not directly observable, but they should be calculable if the true nature of spot structure can be ascertained. Quantitative measures of the intensities of spectral lines in spots should be of assistance to the astronomer in determining the physical conditions within the spot.

Sun-Spot Twins

Next there is the problem of associated sun-spots, pairs and groups being far more common than single ones. Since a vortex must, on simple hydrodynamical theory, possess two ends, each lying in a surface of the medium (or extending to infinity), the well-known "bi-polar" character of doubled spots seems significant. The opposite ends of a single vortex must be right- and left-handed, and the fact that one spot of a pair invariably possesses a pole of sign opposite to that of the other, is strong evidence in favor of the vortex relationship. Even when the second spot is not visible, or perhaps merely indicated by a facular disturbance, it may make itself known through the presence of its magnetic field, which splits the lines of the spectrum. We should like to know more about these invisible spots.

The Sun Rotates Faster at the Equator

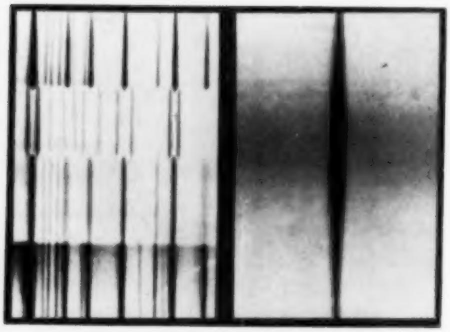
The so-called "equatorial acceleration" of the sun is exhibited by the simple fact that sun-spots near the equator complete a circuit in shorter periods than those nearer the poles. The problem of the maintenance of the drift in the presence of opposing drag of neighboring layers must be studied. It is important to note that mere transport of material from one solar latitude to another should produce quite the opposite effect, as in the terrestrial trade winds. Thus the source of the acceleration is probably very deep-seated, perhaps in a core that rotates much more rapidly than the solar external layers.



Mt. Wilson Observatory.

PHOTOGRAPH OF SUN

NEAR SUN-SPOT MAXIMUM; AUGUST 12, 1917. NOTE, IN ADDITION TO THE SPOT, THE BRIGHT FACULAE WHICH ARE MOST CONSPICUOUS NEAR THE SUN'S EAST AND WEST LIMBS.



Mt. Wilson Observatory.

THE ZEEMAN EFFECT

THE SPLITTING OF SPECTRAL LINES UNDER THE INFLUENCE OF A MAGNETIC FIELD IS CLEARLY SHOWN IN THE LEFT-HAND PHOTOGRAPH. THE ANALOGOUS SPLITTING IN THE SPECTRUM OF THE SUN-SPOT IS SHOWN IN THE RIGHT-HAND RECORD.

Whether we can discover the origin or not of the eastward equatorial current, its mere existence presents numerous unsolved problems connected with sun-spots themselves. A sun-spot pair, with the members in slightly different latitudes, is subjected to an enormous shearing force. The surprising feature is that it does not tend to disrupt spots more seriously. Even a single spot is subject to this peculiar force. In only a day or so a circular spot located in the regions of greatest shear would be markedly distorted into the form of an ellipse, if the sun-spot forces did not oppose the effect caused by relative drift of gases in neighboring latitudes. No evidence of such a distortion now exists, but careful observations might disclose an effect. Such data are important, as indeed are the relative motions of spot members, for they will give information about the fundamental character of the vortices. Theoretically, the filaments of neighboring vortices should interact to produce relative motions.

The Sun's Double Vortex

Finally, there is the question of all the spot groups taken together. Why do spots appear only in the zones between the 40-degree latitude parallels of the solar surface and never in the polar regions? Thus enters the very complex problem of solar variation, as exhibited by sun-spot phenomena. Not only do the numbers show the well-known rise and decline with the eleven-year cycle; there is also the equator-ward drift of the sun-spot zones, as the cycle progresses. We see in this behavior and in the longevity of various spot groups evidence for powerful vortical currents that persist for long periods of time. A full appreciation of the nature of this deep-seated circulation is important if progress is to be made in the problem of sun-spots and solar variability. The opposite magnetic polarities of the preceding and following spots in the northern and southern hemispheres and their reversal at the next cycle shows that the time period is one of 23 years.

The large-scale motion of spots is suggestive indeed that we are dealing with a vortex within a vortex, *i.e.*, a double set of coupled vortices. One governs the formation of individual spots, and the second the cyclic periodicity of spots as a whole. Bjerknes has given an elementary hydrodynamic theory, which is capable of being further developed. It is tempting indeed to suggest that the general magnetic field of the sun is associated with the second type of vortex in the same way that the fields of individual spots are produced by vortices of the first variety. Further studies of this general magnetic field are urgently needed.

Needed Observations

It is apparent that the present program of sun-spot observations is sufficient in certain respects. Through cooperative effort of many observatories in various parts of the world, a regular record is kept of the spottiness of the sun and of the growth and development of groups. Thus the more general features of the problem of spot variations are well

covered. But the foregoing discussion clearly shows the need of more detailed analysis of individual spots and their fluctuations from minute to minute and hour to hour.

The old-fashioned visual solar observers, like Young, Secchi, Langley and Lockyer, have unfortunately almost completely disappeared. They recorded the interesting and peculiar behaviors of individual spots. Visual observers, however, are always at some disadvantage. The changes in spots, though significant in the course of hours, are so slow that the eye may fail to perceive important variations or may misinterpret the others. And, unless the astronomer is also a skilled artist, which is rarely the case, the mere written records fail to do justice to the observations.

Even the ordinary series of photographs often presents difficulties of interpretation. What one really needs is motion-picture recording, with the individual frames well spaced so that the motions are effectively speeded up by a factor, say, of 500 times in projection. The enormous success of Dr. R. R. McMath at the McMath-Hulbert Observatory, of the University of Michigan, in the use of motion-picture technique for spectroheliograms of the solar disk and prominences, shows the power of this mode of recording results. The graphic portrayal of the circulatory and eruptive features of the sun's atmosphere focuses immediate attention upon the truly significant features of the problem. And what Dr. McMath has achieved for the spectroheliograph could be even more easily adapted to direct photography of all kinds. Records of this character should assist astronomers to answer many of the questions raised in the foregoing discussion.

The recent development of new types of filters, made of quartz plates and polaroid sheets, greatly increases the possibilities for direct photography. This device is essentially a monochromatic filter and, if fully developed, would yield results comparable to those now obtained with the spectroheliograph. Evans, at Chabot Observatory, has obtained significant preliminary results with such filters. A combination of one of these filters with interferometers would give on a single photograph a three-dimensional picture of the motions, not only of the apparent drift but also of the speed toward or away from the observer.

The Surface is Granulated

The problems of sun-spots represent only a few of those in solar physics. The relatively clear areas between the spots are not without interest. Under high magnification, the sun's surface is seen to be flecked with myriads of tiny granules, only a few hundred miles in diameter. This granulation is subject to rapid fluctuations, indicative of the turbulent condition of the solar atmosphere. The appearance is not unlike that presented in an airplane view of a stormy sea on which the white-capped waves are dancing up and down. The entire picture may change in the course of a very few minutes. Indeed, very little else is known of the phenomenon, but cinematograph records appropriately taken with films of high contrast should disclose the character of the granulations and reveal the relationship that exists between them and the much larger spots. Observations over a sun-spot cycle, to find out the change of granulation with solar activity, would be particularly interesting.

Near the solar limb are often observed bright streaks or patches known as faculae. Although they are most commonly associated with sun-spots, faculae frequently appear in regions where no definite spots are visible. They may change their form in a space of several hours, yet some regions showing pronounced facular patches may persist for months. Thus, regarded as a form of

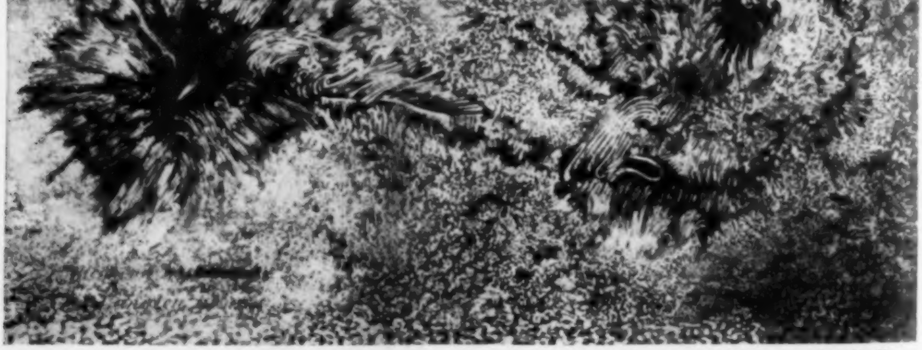
solar activity, faculae are much longer lived than spots. That the two phenomena are closely related, however, is shown by the fact that the disappearance of a spot is customarily followed by the appearance of faculae.

The Mysterious "Mountains" of the Sun

No satisfactory explanation of faculae has ever been given. Some observers have regarded them as a sort of cloud phenomenon, perhaps even a condensation, but this is unlikely. Their increased visibility at the limb, where the observer looks through a greater thickness of atmosphere, indicates that they are higher than the general level of the photosphere, or normal radiating surface. Clearly, more data are needed for their interpretation, but the indications are that they are a bulge in the sun's surface, in effect a "solar mountain." The phenomenon may be more technically described as a region where the atmospheric density is greater than that of the surrounding regions. What force can cause these semi-permanent elevations of the surface is not immediately obvious. It is possible, however, that sub-surface vortex tubes, struggling to preserve their identity under the pressure of overlying gas, might produce the effect. Here again, cinematograph records should help us to unravel the relationship.

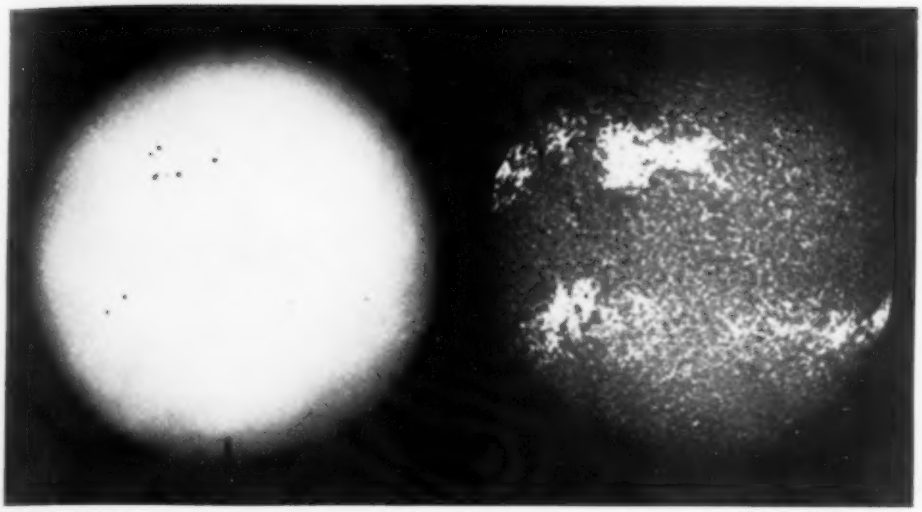
The Turbulence of the Upper Solar Atmosphere

For the analysis of disk phenomena other than spots, granulation and faculae, the spectroheliograph, especially in the form employed at the McMath-Hulbert Observatory, stands unequalled. The surface details revealed by observations taken in the monochromatic light of some spectral line refer in general to higher atmospheric levels than those taken by the ordinary photographic process. The motion-picture records thus far obtained show a turbulence of the solar gases that can be appreciated in no other fashion. An ordinary series of exposures, taken say at fifteen-minute intervals through the day, show changes



Smithsonian Institution.

LANGLEY'S DRAWINGS OF A SUN-SPOT GROUP (1873)



Mt. Wilson Observatory.

COMPARISON OF DIRECT PHOTOGRAPH AND SPECTROHELIOGRAM

IN THE LIGHT OF CALCIUM. NOTE THAT THE CALCIUM FLOCCULI TEND TO FOLLOW THE GENERAL PATTERN OF THE FACULAE RECORDED IN THE DIRECT PHOTOGRAPH.

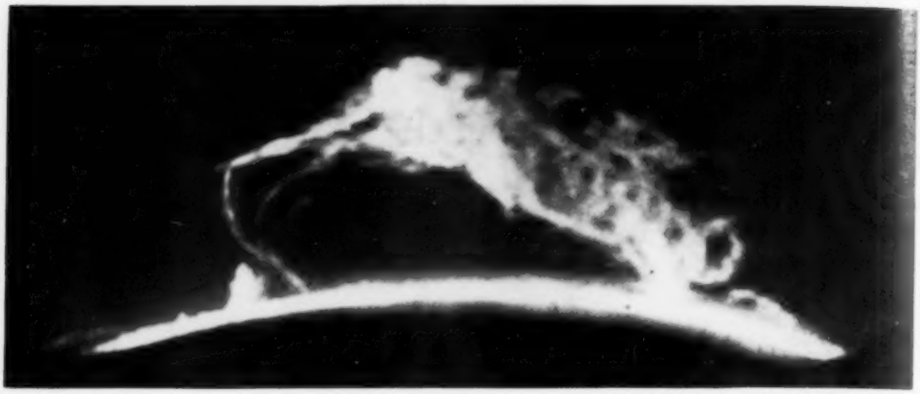
clearly, but the character of the transition stages is completely lost.

The clouds of hydrogen atoms, when the selected monochromatic line corresponds to light emitted by that element, are seen to be in rapid turbulent motion, like waves on a choppy sea. The observations plainly refer to that layer of atmosphere known as the chromosphere, which is best seen at the time of total solar eclipse. It thus appears as a ragged edge made up of spikes and filaments with a large prominence here and there projecting from behind the occulting lunar disk.

The prominences are also visible in projection against the solar disk as irregular absorbing patches sharply delineated against the brighter background. These are the dark "flocculi" of the solar surface. Bright flocculi, particularly prominent in spectroheliograms taken in light of ionized calcium, also exist. The sun-spots, too, appear, but their relatively more stately motions are lost in the general hurly-burly of the sun's upper atmosphere. There is some indication that the bright calcium flocculi respond to the vortex forces, with a slow rotation around the spot area. This reported phenomenon is worthy of more detailed investigation. The faculae and the granulations are completely invisible in ordinary spectroheliograms. The former will reappear if the wavelength region is shifted to a point outside the absorption line, but the resolution of the spectroheliograph is probably insufficient to reveal much of the granulation.

The Solar Spectrum

Of particular significance in any study of the solar surface is the physical interpretation of the spectra of various portions of the sun. Analysis of the intensities of the Fraunhofer lines, studies of their displacements from normal positions as a result of convection currents in the atmosphere, the nature of line profiles over the disk, should continue to be profitable fields of investigation. Spectrographs of large dispersion and high resolving power, with interferome-



McMath-Hulbert Observatory.

AN INTERESTING PROMINENCE

NOTICE THE INTRICATE CHARACTER OF THE DETAIL. THE MOTION OF THE STREAMERS AT THE LEFT IS PREDOMINANTLY DOWNWARD.

ter accessories, should be employed. The studies will eventually culminate in increased knowledge of such important factors as the chemical composition, temperature, pressure and degree of atomic dissociation in the solar atmosphere. They will also give valuable physical data concerning the properties and behavior of atoms and molecules.

"Movies" of Prominences

The motions of prominences are best depicted by observations of the solar limb, with the solar image either occulted by an opaque disk or reduced in intensity by a dark circular filter. The spectroheliograph and the coronagraph stand about equal in their abilities to record these complex phenomena. The observations show that no two prominences are alike in behavior, although several distinct classes appear. Motion-picture technique has revealed what years of direct photography failed to disclose in detail: the intricacies of the prominence motions.

There is no such thing as an absolutely static prominence. All exhibit activity, some to greater degree than others. Those of the quiescent type display a variety of internal circulations, like the convection currents in a fleecy cumulus cloud. Others show evidence of a large-scale rotation, a sort of cyclonic effect, with the predominant motions parallel to the solar surface. Also, there are the common eruptive prominences, where great clouds of gas are blown violently away from the sun, apparently never to return. A fairly common variety consists of an inverted cone of gas, detached completely from the surface, except for "roots" running into the photosphere.

The peculiar and unexpected result of the new cinematograph studies is that the motion is predominantly downward. Since there is little if any evidence that material is being replenished in the main conical body, how the prominence maintains itself is a serious problem. This difficulty is even more graphically presented by still another variety of prominence, which might be described as a sort of reversed fountain. I say "reversed" because the matter is running backward from the top of the stream. Often numerous individual filaments exist, running downward in long graceful curves from a common point, each drawing upon an invisible source for its maintenance. In one remarkable record made at the McMath-Hulbert Observatory, the main body of the prominence springs suddenly into existence high above the

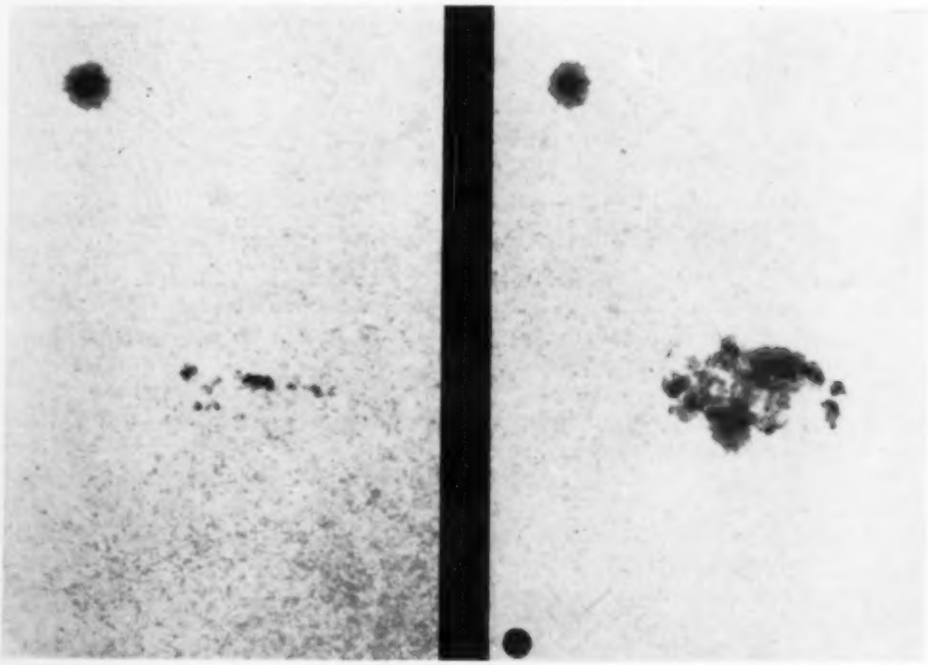
solar surface. The roots are formed as a subsequent development.

There seem to be three possible answers to the question of the origin of prominence material. The substances may be condensing from the corona where conditions render it non-luminous. They may rise invisibly from the photosphere. Or perhaps there are streams of material plying through the upper solar atmosphere, which becomes luminous only when they enter a region of high excitation, perhaps a restricted beam of ultraviolet radiation. The often expressed idea that the effect might be merely an excitation wave analogous to the terrestrial aurora is untenable; for that the motion is of real particles is proved by the magnitude of the observed Doppler displacements.

None of these theories, or at least none of them singly, is sufficient to account for all the observed effects. Further, one meets with serious difficulties in explaining why and how ionized gas should suddenly become luminous unless there is some action causing a rapid increase in its density in the neighborhood of the prominences. Intense force fields of electromagnetic origin might cause matter streaming in from all directions to converge into a certain volume. Charged particles, moving along magnetic lines of force produced by a sunspot, might behave in this fashion, and the afore-mentioned inverted cone is suggestive that the effect may occur. Observations of motions along coronal streamers would help to settle this important question.

Clouds That Weigh Thirty Million Tons

The chromosphere and prominences



Mt. Wilson Observatory.

TWENTY-FOUR HOUR DEVELOPMENT OF A SUN-SPOT GROUP

NOTICE THAT THE SPOT IN THE UPPER LEFT HAS REMAINED PRACTICALLY UNCHANGED WHILE THE GREAT GROUP HAS GROWN ENORMOUSLY. THE SMALL BLACK DOT AT THE BOTTOM REPRESENTS THE SIZE OF THE EARTH.

have many common features. In fact, one might say that a prominence is merely an overgrown chromospheric spike. In both phenomena the outstanding problems of interpretation are similar. How is the mass of a prominence supported for so long a time against the enormous pull of solar gravitation? The motion in the streamers seems to be one of almost uniform velocity, and shows none of the expected acceleration in its sun-ward fall. When accelerations do occur along the path, they arise almost instantaneously and the matter adjusts itself to a new uniform velocity.

The suggestion has been made—and the idea has met with wide acceptance—that pressure of sunlight is responsible for the effect. A quantitative calculation discloses, however, that if radiation pressure is the agent, we shall have to revise completely our conception of the temperature of the solar surface—so widely quoted at 6000°. For the mass of even a small prominence may be conservatively estimated at 1,000,000 tons. If solar gravity alone were acting, the prominences would fall from an initial height of 30,000 miles to the surface in an interval of only ten minutes.

The Lifting Power of Sunlight

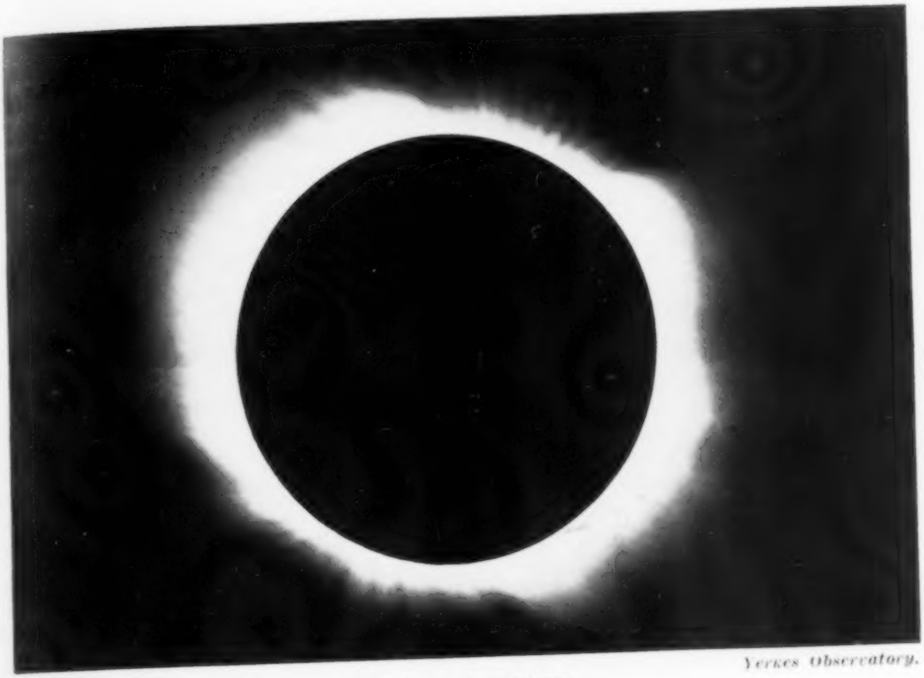
To prevent the collapse of this great tonnage, an enormous amount of radiation is required, far more than the sun could furnish if it were to radiate in all wave-lengths as if its temperature were 6000°. Furthermore, since the radiation must be absorbed if it is to have any effect in support, and since hydrogen, the most abundant constituent of prominences, can absorb radiation effectively only in the spectral regions short of 1,000 Ångstrom units or so, large quantities of energy must be escaping from the sun in the extreme ultra-violet. Our atmosphere, unfortunately for the astronomical observer, is completely opaque to light of this wave-length, so that no direct check can be obtained. But a simple calculation shows that the ultra-violet radiation temperature of the sun must be at least 12,000°, if radiation pressure is the source of support.

Fortunately, there is another observational fact that points toward exactly the same conclusion. The spectra of the chromosphere and prominences, obtained at total solar eclipses, show very intense spectral lines of hydrogen and helium. These elements require a very high degree of excitation before they will shine at all, and theory is conclusive in specifying that the amount of radiation we receive could be produced only by a source with a temperature from 12,000° to 25,000°. The higher figure comes from the calculation for helium.

As a matter of fact, there is a third confirming observational datum of a totally different character. The degree of ionization in the electron layer high in the earth's atmosphere, the layer that is responsible for the reflection of radio waves around the earth, also demands a high radiation temperature for the solar ultra-violet.

We seem forced to conclude, therefore, that abundant radiation is present, and we may provisionally accept the ultra-violet excess of the sun's radiation, although in doing so we are merely replacing one difficulty with another. For then we are led to ask: how can this energy escape from the sun? And why, in passing through the lower levels of the solar atmosphere, does it not produce observable effects in the ordinary absorption spectrum? To neither of these questions has a satisfactory answer been proposed, although the second is by no means as serious as the first. In fact, the latter query may possibly be countered with the statement that the observed intensities of a few absorption lines, like those of oxygen, hydrogen and helium, can be better explained if the excess ultra-violet energy is present.

Merely postulating the existence of radiation pressure, however, falls far short



Yerkes Observatory.

THE SOLAR CORONA

THIS PHOTOGRAPH, TAKEN MAY 28, 1900, IS ILLUSTRATIVE OF THE MINIMUM TYPE OF CORONA, WITH DISTINCT "BRUSHES" NEAR THE POLE AND LONG EXTENSIONS PARALLEL TO THE EQUATOR.

of solving the entire problem of prominence motion. There is the unsolved problem of how so delicate a balance is maintained automatically between radiation pressure and gravity. There is a chance that, if the ultra-violet radiation consists in part of intense emission rather than absorption lines, an equilibrium can be secured. An atom, moving too fast, would be unable to absorb the line, because of the Doppler effect. Its motion would, in consequence, be checked. I confess, however, that the idea borders on the speculative. The uniformity of velocities in most prominences indicates that no persistent accelerations are present, except perhaps those in a direction perpendicular to the motion, as the quasi-circular trajectories of the streaming material indicates. It seems unlikely indeed that either radiation pressure or gravitation can be called on to explain the curved trajectories.

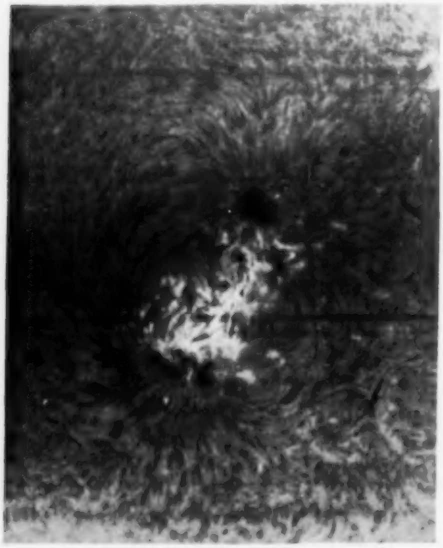
Magnetic Fields May Assist

The curvature suggests that magnetic fields may play a part in the phenomenon. There are two partial explanations available. It is well known that the motion of electrified particles in a magnetic field is perpendicular to the magnetic lines of force. Are the great curved trajectories, then, produced by the circling of electrons around a magnetic field more or less parallel to the solar surface? The radius of the trajectory is inversely proportional to the field intensity. The fields thus calculated are so very minute that one would scarcely expect them to set up the electric currents that must necessarily accompany such action.

If the motion of the matter is toward the right, let us say, the electrons would have to flow to the left. And since the material must be neutral as a whole, the matter can not move until a complete

electric circuit is established. A prominence so constituted would consist of matter streaming upward from the photosphere, reaching a maximum and finally descending. The resultant motion is so unprominence-like that we may discard the idea.

The second possibility is more promising. Suppose that an intense magnetic field, *e.g.*, that of a sun-spot, is in the neighborhood. The lines of force, curving from the spot toward the prominence, will be very nearly parallel to the solar surface in this region. In the intense magnetic field electrons will whirl in very tiny orbits, a few millimeters in diameter. The ions will traverse somewhat larger orbits in the opposite direction, but there will be no charge separation, because the orbits are so small. The magnetic field exerts a sort of stabilizing action and neither gravitation nor radiation pressure can act in normal fashion. There results a sort of gyroscopic action. A sudden blast of radiation would cause the atom to move, not upwards, but in a direction perpendicular to the magnetic lines of force, *i.e.*, essentially parallel to the solar surface.



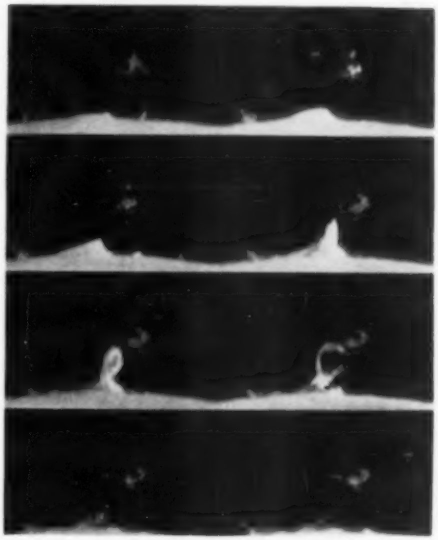
Mt. Wilson Observatory.

BIPOLAR SPOT GROUP

THE DARK HYDROGEN MARKINGS SHOWN ON THE SPECTROHELIOGRAM EXHIBIT A PATTERN RESEMBLING THAT OBTAINABLE IN THE LABORATORY FROM IRON FILINGS SPRINKLED ON A PAPER SUPERIMPOSED ON THE POLES OF A HORSE SHOE MAGNET. THERE IS A POSSIBILITY THAT THE INTENSE MAGNETIC FIELD OF THE SUN-SPOTS MAY PRODUCE THE EFFECT. EVEN THOUGH THE HYDROGEN THAT EMITTED THE LIGHT HERE RECORDED IS NEUTRAL, A FAIRLY LARGE PROPORTION OF THE ATOMS ARE IONIZED AND THEREFORE SUBJECT TO THE FORCES OF THE MAGNETIC FIELD. NOTE THE BRIGHT HYDROGEN FLOCCULI BETWEEN THE PAIR OF SPOTS. THIS ZONE IS PROBABLY AN AREA OF INTENSE PROMINENCE ACTIVITY.

Although interatomic collisions tend to complicate the problem, the predicted effect is enough like that observed in prominences to warrant further investigation. In fact, the observations indicate that prominences, at least some of which have definite vortical character, may also possess magnetic fields. And the very common appearance of double prominences, connected with an overlying arch, may well be analogous to a bipolar spot. The tendency of such objects to "erupt" eventually may possibly arise from a dying of the associated magnetic fields. The so-called sunspot type of prominence, consisting of semi-periodic ejections and withdrawals of flame-like tongues, is further evidence in favor of this picture. Also should be mentioned the peculiar striations exhibited by the bright and dark flocculi in the neighborhood of spots—structure similar to that of iron filings in the vicinity of a magnet. Of course the hydrogen photographs are taken in the light of a neutral atom, but one should recall that the gas is ionized a large part of the time and hence subject to the forces here described.

It should be emphasized that the magnetic fields merely influence the motion. They provide no acceleration in the direction the particle is moving. Atoms are free to slide up or down, *parallel* to the lines of magnetic force, and react



McMath-Hulbert Observatory.

LIFE AND DEATH OF A PROMINENCE

THIS SELECTION OF VIEWS FROM A COMPLETE MOTION-PICTURE RECORD SHOWS THE TREMENDOUS DISTURBANCE RISING FROM THE LOWER CHROMOSPHERE, THROWING OUT A BRILLIANT LOOP WHICH LATER DIES AWAY. MEANWHILE, THE SUSPENDED CLOUD PROMINENCE, WHICH PROBABLY LIES WELL IN FRONT OF THE RECORDED DISTURBANCE, SHOWS ONLY MINOR CHANGES.

naturally to the component of any other force that is exerted in this direction. Near a spot, where the lines are nearly vertical, the field exerts little or no supporting action. The sun's general magnetic field may also play a part.

Whether electric fields exist or not is still an open question. The charge of the earth is far greater than one would expect to find on the basis of simple equilibrium theory. One can not now definitely rule out the existence of similar fields on the sun. They may be large enough to exert an appreciable effect on the motions of prominences, though they probably do not contribute appreciably to the support of the atmosphere.

This tentative theory suggests a multiplicity of observational problems: study of the curvature of prominence streamers, their relation to one another and to neighboring spots, measurements of the patterns exhibited by flocculi near spots, and perhaps even the detection of the Zeeman splitting of prominence lines in the magnetic fields. There is room, also, for allied theoretical studies, such as prominence vortices, the nature and origin of the magnetic fields, etc.

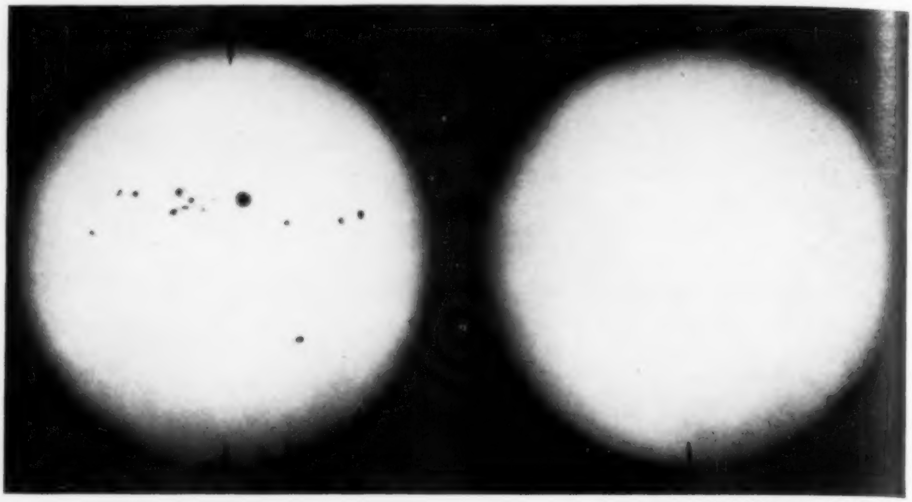
Problems of the Solar Corona

One must not forget that the prominence motions occur in a medium that is far from being a perfect vacuum, *viz.*, the solar corona. All too little is known of this interesting portion of the solar atmosphere. The emission lines have not been identified with those of any known element, although they are undoubtedly due, not to a new substance, but to a familiar one in some special condition of excitation.

The corona consists of a very extensive envelope of gas, in which streamers and condensations in the form of ribbon-like filaments exist. The form is roughly symmetrical about the axis of rotation, with the greatest extensions occurring usually over the spot zones. In the corona, as in prominences, the characteristic pattern is again suggestive of the influence of a magnetic field.

Essentially nothing is known of internal coronal motions. It probably rotates as a whole, along with the sun; radial expansion probably exists. The strong curvature of the filaments in the neighborhood of sun-spots suggests that rapid changes may occur. But the difficulty of observation has made it impossible for us to determine much else except its general variation with the sun-spot period.

The development of the coronagraph and coronaviser have opened new fields for observation and interpretation. Lyot's pioneer work, in France, proved so successful that two similar instruments have been built, one by Waldmeier, in Switzerland, and one by Harvard Ob-



Mt. Wilson Observatory.

THE SUN AT TIMES OF MAXIMUM (LEFT) AND MINIMUM SPOTTEDNESS

servatory, now stationed at Climax, Colorado, at an altitude of 11,500 feet. With these instruments, fairly regular observations should be possible of at least the inner corona. Cinematograph records should disclose the nature of internal motions and their relation to those of the prominences.

It is now known that there exist prominences of purely coronal nature, rich in light of the unidentified lines, but lacking the customary chromospheric radiations. These prominences are known to be associated with regions of high excitation in the chromosphere, and further investigation of the problem should be possible with the coronagraph. Spectrographic observations to search for new lines and provide better wave-lengths of the old ones, will assist in the identification of the atoms responsible for the mysterious radiations. As previously mentioned, the coronagraph is a powerful instrument for the study of prominence motions.

The lower corona, the prominences and even the chromosphere are intermingled. The coronal lines attain their greatest intensity within the boundaries of the chromosphere. Hence, as mentioned above, the resistance of the corona to prominence motions, the effects of viscosity, must be studied. The possibility exists that prominence motions can not be considered separately at all, and that one must treat the flow of gases in the sun's extensive atmosphere as a problem in gaseous hydrodynamics.

The Quantity of Solar Radiation

There is one final and extremely important aspect of solar observation: the question of the quality and quantity of the sun's radiation. Here, indeed, is presented one of the most complicated of all the observational problems. The difficulties are imposed, not by the sun itself, but by the extreme accuracy required and by the earth's atmosphere, through which we must make our measurements. We must correct for the absorption caused by the various constituents of the atmosphere. The technique is far from simple, and great credit must go to C. G. Abbot, of the Smithsonian Institution, for his long and careful investigation of the problem.

His results may be briefly summarized.

In the spectral region accessible to observation, the sun's energy curve corresponds closely to that of a black radiator at temperature of about 6,000° Absolute. There is some discrepancy in the ultra-violet, where the solar radiation is somewhat less than expected, perhaps because of the large number of intense overlapping absorption lines. The total radiation is estimated by interpolation and extrapolation over the absorption bands produced by molecules of the earth's atmosphere. The value of this total energy is known as the solar constant.

In the strictest sense, the figure is not constant. Abbot has shown that the amount fluctuates by about one per cent. Some periodicities are indicated, the best substantiated being cycles of approximately eleven years and of eleven months, respectively. The former, clearly, is associated with the sun-spot variation. Larger fluctuations in the magnitude of the ultra-violet energy have been suspected but not confirmed because of the difficulty in elimination of the absorption of the earth's atmosphere.

The earth's atmosphere! A perpetual nightmare to astronomical observation! From the standpoint of terrestrial life, it is perhaps provident that atmospheric ozone absorbs the far ultra-violet. None whatever of radiation short of about 2,800 Ångstroms penetrates the ozone shell. We might as well be living in a dark cellar, for all the solar radiation that comes through in this spectral range.

And yet this radiation is highly important from the terrestrial point of view. As I previously stated, it is chiefly responsible for the electrification of the atmospheric layer that reflects radio waves. Our estimates of the quantity of this far-ultra-violet energy must

FREMONT PASS STATION, HARVARD OBSERVATORY, CLIMAX, COLORADO

THIS BUILDING HOUSES THE NEW CORONAGRAPH, WHICH HAS JUST BEEN INSTALLED. THE UNUSUAL SHAPE OF THE "DOME" WAS CHOSEN BECAUSE OF THE HEAVY SNOWFALL, WHICH AVERAGES ABOUT TWENTY FEET PER YEAR AT THE ALTITUDE OF 11,500 FEET.

be largely inferential. Abbot assumes that the solar curve follows that of a black radiator at 6,000°, with a depletion of about 70 per cent., and thus deduces a correction of about 4 per cent. to be added to the measured energy.

On such an assumption the energy lying in the extreme ultra-violet, at 1,000 Ångstrom units and beyond, is negligible —about one millionth of the whole. Nevertheless, if the sun radiates in this spectral region as if its temperature were 12,000° or higher, as the excitation of the hydrogen chromosphere and ionosphere seem to demand, an additional factor is required, which may amount to several per cent. Further, radiation in this particular region may fluctuate enormously with solar activity. Apparently the only way open for investigating it at present is from observations of the spectrum, or possibly also from study of the solar corona.

Investigation of the solar constant should be continued, both by the methods developed at the Smithsonian Institution and by any new experimental procedures that can be devised to determine the troublesome atmospheric corrections. Brian O'Brien and his colleagues at the University of Rochester make use of airplanes and balloons to eliminate the lower atmospheric levels. Such studies are profoundly important.

The Sun and the Earth

There is scarcely one of all the foregoing phases of solar research mentioned in the foregoing discussion that does not have some bearing on the interesting problem of solar-terrestrial relationships. For all contribute to our knowledge of the sun and how it operates. The results of the investigations outlined point directly to a determination of the quantity and quality of solar radiation and of the various corpuscular emissions, ions and electrons, some of which may reach the earth.

The picture will be complete only if the physicist, the radio-engineer, the geophysicist and the meteorologist are brought into close collaboration. There are the ionosphere problems, so closely allied with magnetic storms and aurorae. And, finally, there is the ever-significant question of the relationship between solar variability and weather phenomena. The foregoing researches should give new indices, perhaps far more sensitive than sun-spots, for estimating the state of solar activity. And, what is even more important, they may provide a basis for a definite physical tie-up between the sun and variable weather phenomena. Such a conclusion would be of great assistance in guiding the statistician who seeks to correlate "weather" on the sun with that on the earth.

THE ELECTRON MICROSCOPE

By THEODORE A. SMITH
ENGINEERING PRODUCTS DIVISION, RCA MANUFACTURING COMPANY

ALTHOUGH announcement of the development of electron microscopes to a point where they might be applied to scientific research problems is still relatively new, already instruments are being manufactured for the leading scientific laboratories in the United States. In addition, those who have had the opportunity to use electron microscopes have reported a number of interesting discoveries which are indications of what may be expected in the future when further research work has been done.

Before the advent of the electron microscope, information regarding objects too small to be seen could be obtained only indirectly, by estimating sizes, by the use of spectroscopic means or the ultra centrifuge. Naturally, data on the size, shape or distribution of colloidal particles, the structure of plastics and similar information would be valuable to industry. There is every reason to believe that many virus bodies, too small to be seen with optical microscopes, may be responsible for diseases. The electron microscope opens up fields of research in the world of the very small which may be of inestimable value to humanity.

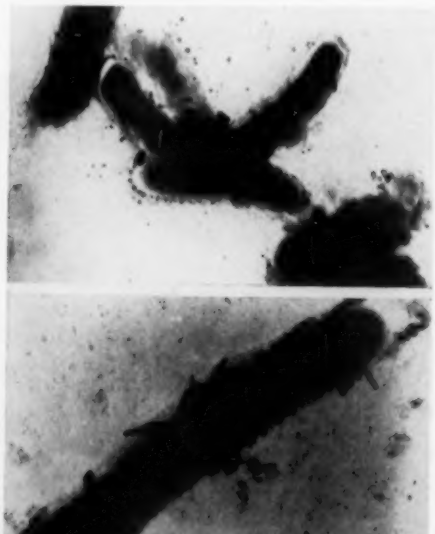
Why can not such small particles be seen with optical microscopes? Reasons why this is the case will make clear the need for a new type of microscope.

Ordinarily, two points separated by a

STREPTOCOCCUS BETA HAEMOLYTICUS MAGNIFIED 24,000 DIAMETERS

THE ORIGINAL MICROGRAPH SECURED WITH THE POWERFUL ELECTRON MICROSCOPE GAVE A MAGNIFICATION OF 45,000 DIAMETERS. AT THIS MAGNIFICATION A HUMAN HAIR WOULD HAVE A DIAMETER OF MORE THAN 10 FEET.

distance less than 0.2 millimeters are not visible as discrete points but will be seen only as a single blur. By the use of a simple magnifying glass, it is possible to extend the range of observation downward about ten times so that it is possible to distinguish points separated by about .02 millimeters. A simple magnifying glass may even be carried further, and it is interesting to note that Leeuwenhoek (who is usually credited with the invention of the microscope) used a simple magnifying glass for his observations and was able to distinguish many animalcules, although he apparently had exceptional eyesight. The use of the compound microscope extends the range of visibility to objects 1,000 times smaller than could be seen with the unaided eye. This means that with the ordinary instrument, points separated by .0002 millimeters may be observed.



TUBERCULOSIS BACILLI

Above: HUMAN BACILLUS MAGNIFIED 22,000 DIAMETERS, SHOWING HITHERTO QUITE UNKNOWN DETAILS. THE ORIGINAL MAGNIFICATION WITH THE RCA ELECTRON MICROSCOPE WAS 42,000. *Below:* BOVINE BACILLUS MAGNIFIED 44,000 DIAMETERS. REDUCED FROM A MICROGRAPH HAVING A MAGNIFICATION OF 84,000 DIAMETERS.

In the extension of the range of vision up to magnifications of 1,000, the principal limitations are those caused by optical deficiencies in the lenses which may be minimized by special lens formulas. However, above magnifications of 1,000 a new limitation creeps in; namely, the wave-length of the medium used to view the specimens, that is to say, light, itself.

The wave-length of light in the visible range is in the order of .0004 to .0008 millimeters, and it will be apparent that many of the bacteria or other objects which scientists wish to examine are smaller than this value. Mr. Hillier, of Dr. Zworykin's electron research group who have been responsible for the development of this instrument, offers an interesting parallel which helps to make this point clear. If we drop a stone into a small pond causing ripples to radiate from it in all directions and if these ripples chance to strike a vertical stake in the pond, a disturbance will be caused in the regularity of the ripples as they pass the stake. However, as the wavelets pass beyond the stake, the disturbances are smoothed out, so that several feet away the wavelets are nearly parallel and it is difficult to tell that the stake had interrupted their passage at all.

Now, things are seen due to their disturbing effect on light waves. If no disturbance is produced, we can not see them. Therefore, if objects are much smaller than the wave-length of the medium used to observe them, whether it be water or light, they produce a disturbance which is very small and, hence, can not be easily detected. If, instead of a small stake in the pond, we had observed the effects of a boat shadowing the waves radiated by the dropping of a stone, we would discover that beyond the boat the waves were entirely obscured or, in other words, the effect of the boat was to disturb the waves to a considerable degree.

Thus, objects much larger than the observing medium will produce an effect which may easily be detected and this, of course, is what permits us to see everyday objects.

One solution, of course, is to employ light of shorter wave-lengths, and this has been carried forward in the ultra-violet type of microscope so that a magnification of approximately 2,500 is possible; this permits us to observe particles separated by a distance of slightly less than .0001 millimeters.

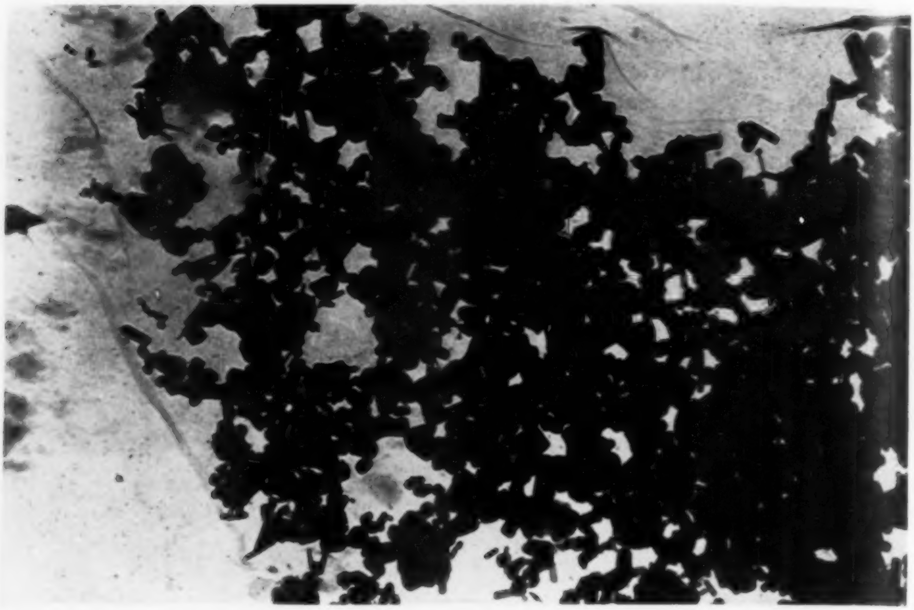
Other means also exist for stretching the range of the optical type microscope, but they can not be extended indefinitely so that it appears that the scope of seeing smaller and smaller objects by means of light is definitely limited to a useful magnification of approximately 2,500 diameters. If we go above this point and magnify to a greater extent, we do not discover any new detail but merely make the resulting image larger. As long as the image can be made as big as .2 millimeters, we do not gain any new information by further enlargement.

The electron microscope represents a means to extend the scope of seeing to smaller objects. It makes use of a stream of electrons with which is associated a wave-length many times smaller than even that of ultra-violet light. In fact, the wave-length of an electron beam, having a velocity of 60 kilovolts, such as is used in the commercial type electron microscope, is small enough so that theoretically it should be possible to see atoms.

Other effects, however, prevent this enormous resolution from being realized, but, practically, it is possible to observe large molecules; and magnifications up to approximately 100,000 may be employed before exhausting the detail permitted by this medium. In other words, instead of a limitation of observing particles separated by a distance of .0001 millimeters, we can now observe particles separated by a distance of .000002 millimeters so that we have extended the range of seeing to things 1/50 of the minimum size observable with the best light microscope.

THE NEW ELECTRON MICROSCOPE
BEING USED BY DR. V. K. ZWORYKIN, STANDING, DIRECTOR OF ELECTRON RESEARCH OF THE RCA LABORATORIES, AND JAMES HILLIER, SEATED, CO-DEVELOPER OF THE NEW ELECTRON MICROSCOPE.

Obviously, with a stream of electrons it is impossible to employ the ordinary type of lenses which are used in the more familiar microscope since electrons do not pass through very thick or dense materials. However, a magnetic field produced by a coil with a current flowing through it will deflect a stream of electrons and by properly designing the coil, it may be made to act as a converging lens does and, hence, to produce an image of the disturbance caused when electrons pass through the material to be examined. In the RCA electron microscope three such lens structures are employed. The first serves as a magnetic condenser lens, having a function similar to that of the sub-stage condenser in an ordinary microscope; the second lens produces a magnification of approximately 100 times and acts as a magnetic objective lens. The third mag-



ELECTRON MICROGRAPH SHOWING APPEARANCE OF ZINC OXIDE PIGMENT
MAGNIFICATION ABOUT 24,000 DIAMETERS; ORIGINAL MAGNIFICATION, 44,000 DIAMETERS.

A FAMILIAR BACTERIUM—AERO BACTERIUM CLOACAE
MAGNIFICATION ABOUT 30,000 DIAMETERS; ORIGINAL MAGNIFICATION, 54,000 DIAMETERS.

netic lens acts as an image projector and provides additional magnification which may be required to bring the detail to a size which may be readily observed. The electron stream is generated by a heated filament similar to that in a radio tube and since molecules of air would interfere with the normal passage of electrons, vacuum pumps exhaust the chamber to a pressure corresponding to about 10^{-5} millimeters of mercury.

When the electron stream passes through the object to be examined, the denser portion of the material will cause the electrons to be scattered in various directions. The more dense the substance, the more scattering will take place and, hence, fewer electrons from this portion of the specimen can get through the aperture in the objective and reach the viewing screen. In addition, if the atoms of a particular material are heavy they will also serve to deflect more electrons than if they were light. Thus, the image formed by the electron stream is built up due to the atomic weight and the density of the substance being examined.

Electrons are entirely invisible, but if the stream is permitted to strike a fluorescent screen an image will be created of light and dark portions corresponding to the electron density. Hence, in the electron microscope the image is seen not by direct observation but by looking at the pattern produced on the fluorescent screen. Electrons will also affect a photographic plate in the same manner as light and, if the fluorescent screen is removed and a photographic plate substituted, it is possible to obtain a permanent record. Such pictures can not be called photographs since they are not produced by light but have been termed micrographs.

Although it is necessary to introduce the specimens into a vacuum while observations are being made, air locks are provided which allow air to enter only a small chamber which may be pumped out separately so that the vacuum of the entire instrument is not spoiled. It is possible to move the specimen about in order to examine various portions of the field and, in fact, the procedure of taking a micrograph with the electron microscope is actually simpler in some respects than the equivalent procedure when using an optical instrument. For example, in several instances it has been possible to obtain negatives of the material under observation which had been brought into the laboratory in a test-tube only ten minutes before.

Since a high voltage is required to accelerate the electrons and to cause them to travel in straight lines, it is important that this voltage be constant or the resulting picture will be blurred. Dr. A. W. Vance has designed an extremely stable power supply system which greatly reduces these fluctuations and permits long-time exposures without blurring.

The entire unit is contained in a structure comprising a metal rack containing the power supply equipment and a column in front of the rack which is the microscope tube, itself. The electron microscope is focused by varying the current through the magnetic lenses and this control, as well as the magnification controls, is mounted on the front panel of the power supply rack. With the exception of a vacuum fore pump, the microscope is self-contained and operates from a 110 volt, AC supply requiring only about 2.5 kw power.

As an indication of the simplicity of its use, it has been possible to bring persons who are acquainted with laboratory procedure, but who had never used the electron microscope before, to the instrument and to have them taking pictures with it two or three hours after they first see it.

Because of this simplicity in operation, it is expected that research and development work will be facilitated and it is hoped that much of importance may be disclosed which now lies beyond the range of visibility.

HOW DARWINISM CAME TO THE UNITED STATES

By Professor W. M. SMALLWOOD

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It is interesting to drop back to the first meeting of Charles Darwin and Asa Gray, which took place in London. This event, simply recorded by Asa Gray in his journal on January 22, 1838, gives no intimation of the important series of happenings which were to follow two decades later: "We there met Mr. Darwin, the naturalist who accompanied Captain King in the *Beagle*."[1] Professor Gray made his first voyage to Europe while on a leave of absence from the newly established University of Michigan.

Thirteen years later, early in 1851, when Professor and Mrs. Gray made a journey to Europe, Mrs. Gray wrote in her diary the following account of the second meeting of those two great men:

> And one day came an invitation to lunch from the Hookers', 'to meet Mr. Darwin, who is coming to meet Mr. Hooker; is distinguished as a naturalist.' Mr. Darwin was a lively, agreeable person.[2]

Owing to the strange ways of mice and men, there seems to be no way of learning what influenced Gray to begin writing to Darwin, and Darwin to continue the correspondence. We read that Gray's letters to Darwin previous to 1862 were mostly destroyed, and those of a later date more or less injured by mice.[3] It is impossible to do more than outline the influences that led Darwin to take Gray into his confidence after two casual meetings. This was an honor which had been extended to but two Englishmen—Joseph D. Hooker and Sir Charles Lyell.

Gray had written some of his philosophic conclusions about "species" to Hooker in 1854, noting that "scientific Systematic Botany" rests upon species "created with almost infinitely various degrees of resemblance among each other." This unpublished letter[4] indicates that there is variation in some species; and, because of its importance in almost anticipating Darwin, is quoted rather fully:

> But who shall lay down a rule as to *how much* two plants shall differ in order to be admitted as specifically different? That must be determined by observation and experience alone:—which show that while some species are *extremely polymorphous*, others, that we doubt not are distinct, differ constantly in one or two particulars which experience proves to be of no moment at all in analogous cases. (If it be said that it is not likely the Creator should originate two species with so trifling a difference between them, I would suggest that the marks we define a species by do not *constitute* the species; they are only the convenient 'outward and visible sign of an inward grace,').

One would have more confidence in Gray's grasp of the significance of variation, if he had omitted the above sentence which he placed in parentheses. He continued:

> When we find two . . . representative forms geographically connected by intermediate stations—the differences, such as they are, . . . is a question to be decided either way, with more or less probability, according to our best judgment on the case, but we cannot pretend to decide it with anything like certainty. But if, with the mingling or approximation of the areas we find a shading off of the differences, then it

1 For a detailed description of this meeting, see "Letters of Asa Gray," Jane Loring Gray, editor (Boston and New York, 1893), I, 117.

2 "Letters of Asa Gray," II, 380.

3 *Ibid.*, 454.

4 For a copy of this letter, written by Asa Gray from Cambridge, Massachusetts, February 21, 1854, the author wishes to thank Dr. M. L. Green, of the Herbarium at the Royal Botanic Gardens, Kew, Surrey, England, where the original letter is deposited.

is far more likely that they all belong to one species. . . .

And this leads me to two points that I must have boggled in my former letter: for as they stand in my mind, I see no real contradiction between them, *viz.* the general and fundamental law of *genetic resemblance*, and the exceptional, *inexplicable* (we should call it impossible antecedently to the fact) origin of *races*, which, once originated, equally follow the law of genetic resemblance, show the strongest tendency to reproduce the parental features or peculiarities,—though this be partly overborne by the tendency to revert to the original type—but more generally obliterated by intermixture of stock.

In the same letter, Gray raised the question of variation:

Unisexual trees, you observe, are not more variable than hermaphrodite ones. Did it ever occur to you that they *should be less variable because* unisexual—the inevitable mingling of stock preventing the continuance of individual peculiarities? And consider, also, how many more plants than is generally thought are subpolygamous or subdioecious,—the stamens more vigorous in one individual, the pistil in another.

The complete letter was sent to Darwin soon after Hooker had received it, according to the following communication which Hooker had from Darwin, written on March 26, 1854. Darwin's closing sentence was especially revealing:

I am particularly obliged to you for sending me Asa Gray's letter; how very pleasantly he writes. To see his and your caution on the species-question ought to overwhelm me in confusion and shame; it does make me feel deuced uncomfortable. . . . I was pleased and surprised to see A. Gray's remarks on crossing, obliterating varieties, on which, as you know, I have been collecting facts for these dozen years. How awfully flat I shall feel, if when I get my notes together on species, etc., etc., the whole thing explodes like an empty puff-ball.[5]

It was in April of the next year that Darwin wrote his first letter to Gray, incidentally stating: "I may premise that I have for several years been collecting facts on 'variation,' and when I find that any general remark seems to hold good amongst animals, I try to test it in Plants."[6] He continued with a request for information regarding Alpine plants. There was no reference made to the above-mentioned letter which Gray had written to Hooker.

Early in 1856, Lyell urged Darwin to write out his views on the origin of species; and in July of that year we learn that Darwin was cautiously sounding out Gray:

It is not a little egotistical, but I should like to tell you (and I do not *think* I have) how I view my work. Nineteen years (!) ago it occurred to me that whilst otherwise employed on Nat. Hist., I might perhaps do good if I noted any sort of facts bearing on the question of the origin of species, and this I have since been doing. Either species have been independently created, or they have descended from other species, like varieties from one species. . . . But as an honest man, I must tell you that I have come to the heterodox conclusion that there are no such things as independently created species—that species are only strongly defined varieties.[7]

A little more than a year was to pass before Darwin wrote Gray a still more significant letter, in which he summarized the theory of natural selection, and requested secrecy:

You will, perhaps, think it paltry in me, when I ask you not to mention my doctrine; the reason is, if any one, like the author of 'Vestiges,'[8] were to hear of them, he might easily work them in, and then I should have to quote from a work perhaps despised by naturalists, and this would greatly injure any chance of my views being received by those alone whose opinions I value.[9]

In this brief paper it is impossible to reproduce more than a part of Darwin's

[5] "Life and Letters of Charles Darwin," Francis Darwin, editor (New York, 1897), I, 403.

[6] This is the first letter Darwin wrote to Gray. See "Life and Letters," I, 420.

[7] *Ibid.*, 437.

[8] Robert Chambers, "Vestiges of the Natural History of Creation" (New York, 1845).

[9] *Journal of the Proceedings of the Linnæan Society* (London, 1859), xxx, 51. For a brief extract, see "Life and Letters," I, 477; also a footnote added by Francis Darwin with reference to the date of this letter, which "Life and Letters" printed as "Sept. 5 [1857]."

letter of September 5, 1857, which, though it contained many closely written pages, Darwin called a "*most* imperfect" sketch, telling Gray that "your imagination must fill up very wide blanks." It contained the first statement of Darwinism to come to the United States; secondly, Gray really had in his possession the conclusive evidence that Darwin had formulated his theory prior to that of Alfred Russel Wallace, whose letter from Ternate was dated February, 1858. Thirdly, this outline of natural selection sent to Asa Gray indicated either that Darwin had confidence in him, or that he wished to protect his hypothesis from being anticipated by Gray. Fourthly, Asa Gray thus had two years to reflect on the implications of natural selection before he undertook to expound and defend it. This gave Gray a distinct advantage in the Darwinian controversy.

Students of the history of American biology, especially those interested in what Darwin regarded as the essence of his theory, will be glad to have easy access to this abstract of his letter, written from his home at The Downs:

It is wonderful what the principle of selection by man, that is the picking out of individuals with any desired quality, and breeding from them, and again picking out, can do. Even breeders have been astounded at their own results. They can act on differences inappreciable to an uneducated eye. Selection has been *methodically* followed in *Europe* for only the last half century; but it was occasionally, and even in some degree methodically, followed in the most ancient times. There must have been also a kind of unconscious selection from a remote period, namely in the preservation of the individual animals (without any thought of their offspring) most useful to each race of man in his particular circumstances. The 'roguing,' as nurserymen call the destroying of varieties which depart from their type, is a kind of selection. I am convinced that intentional and occasional selection has been the main agent in the production of our domestic races; but however this may be, its great power of modification has been indisputably shown in later times. Selection acts only by the accumulation of slight or greater variations, caused by external conditions, or by the mere fact that in generation the child is not absolutely similar to its parent. Man, by this power of accumulating variations, adapts living beings to his wants—may be said to make the wool of one sheep good for carpets, of another for cloth, etc. . . .

I think it can be shown that there is such an unerring power at work in *Natural Selection* (the title of my book), which selects exclusively for the good of each organic being. The elder De Candolle, W. Herbert, and Lyell have written excellently on the struggle for life; but even they have not written strongly enough. Reflect that every being (even the elephant) breeds at such a rate, that in a few years, or at most a few centuries, the surface of the earth would not hold the progeny of one pair. I have found it hard constantly to bear in mind that the increase of every single species is checked during some part of its life, or during some shortly recurrent generation. Only a few of those annually born can live to propagate their kind. What a trifling difference must often determine which shall survive, and which perish!

Now take the case of a country undergoing some change. This will tend to cause some of its inhabitants to vary slightly—not but that I believe most beings vary at all times enough for selection to act on them. Some of its inhabitants will be exterminated; and the remainder will be exposed to the mutual action of a different set of inhabitants, which I believe to be far more important to the life of each being than mere climate. Considering the infinitely various methods which living beings follow to obtain food by struggling with other organisms, to escape danger at various times of life, to have their eggs or seeds disseminated, etc., etc., I cannot doubt that during millions of generations individuals of a species will be occasionally born with some slight variation, profitable to some part of their economy. Such individuals will have a better chance of surviving, and of propagating their new and slightly different structure; and the modification may be slowly increased by the accumulative action of natural selection to any profitable extent. The variety thus formed will either coexist with, or, more commonly, will exterminate its parent form. An organic being, like the woodpecker or misseltoe, may thus come to be adapted to a score of contingencies—natural selection accumulating those slight variations in all parts of its structure, which are in any way useful to it during any part of its life.

Multiform difficulties will occur to every one, with respect to this theory. Many can, I think, be satisfactorily answered. *Natura non facit saltum* [Nature does not make leaps] answers some of the most obvious. The slowness of the

change, and only a very few individuals undergoing change at any one time, answers others. The extreme imperfection of our geological records answers others.

Another principle, which may be called the principle of divergence, plays, I believe, an important part in the origin of species. The same spot will support more life if occupied by very diverse forms. We see this in the many generic forms in a square yard of turf, and in the plants or insects on any little uniform islet, belonging almost invariably to as many genera and families as species. We can understand the meaning of this fact amongst the higher animals, whose habits we understand. We know that it has been experimentally shown that a plot of land will yield a greater weight if sown with several species and genera of grasses, than if sown with only two or three species. Now, every organic being, by propagating so rapidly, may be said to be striving its utmost to increase in numbers. So it will be with the offspring of any species after it has become diversified into varieties, or subspecies, or true species. And it follows, I think, from the foregoing facts, that the varying offspring of each species will try (only few will succeed) to seize on as many and as diverse places in the economy of nature as possible. Each new variety or species, when formed, will generally take the place of, and thus exterminate its less well-fitted parent. This I believe to be the origin of the classification and affinities of organic beings at all times; for organic beings always *seem* to branch and sub-branch like the limbs of a tree from a common trunk, the flourishing and diverging twigs destroying the less vigorous—the dead and lost branches rudely representing extinct genera and families. . . .[10]

J. D. Hooker had been in Darwin's confidence for many years, during which time he had become a believer in natural selection; but, because of the pledge to secrecy, had been forced to retain the creation hypothesis in his writings. Hooker, writing to Gray from Kew, on October 20, 1858, revealed his early acceptance of natural selection:

Most thankful I am that I now can use Darwin's doctrines—hitherto they have been secrets I was bound in honor to know, to keep, to discuss with him in private—& to combat if I could in private—but never to allude to in public, & I had always in my writings to discuss the subjects of creation, variation, etc., as if I had never heard of Natural Selection, which I have all along known & felt to be not only useful in itself as explaining many facts in variation, but as the most fatal argument against 'Special Creation,' & for 'Derivation' being the rule for all species.[11]

Hooker thus told of the embarrassment which Darwin's confidence had caused him. Gray was placed in a similar position, though for a much shorter period. For some time he had been comparing the flora of Japan with that of the United States. It was on December 14, 1858, that he read a notable paper on the distribution of similar species of plants in the two countries. In a footnote, probably added while the paper was going through the press, Gray became specific, but did not reveal that he had received confidential information from Darwin: "The only noteworthy attempt at a scientific solution of the problem . . . is that of Mr. Darwin and (later) of Mr. Wallace. . . . But I am already disposed, on these and other grounds, to admit that what are termed closely related species may in many cases be lineal descendents from a pristine stock."[12]

If it is permissible to draw an inference, it seems clear that the conservative Asa Gray would not have added this note unless he had become convinced, through

[10] *Journal of the Proceedings of the Linnæan Society:* "On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection," by Charles Darwin, Esq., F.R.S., F.L.S., and F.G.S., and Alfred Wallace, Esq. Communicated by Sir Charles Lyell, F.R.S., F.L.S., and J. D. Hooker, Esq., M.D., V.P.R.S., F.L.S., etc. These letters were read on July 1, 1858. First came a letter signed by Lyell and Hooker. Enclosures were: (1) Extracts from the Ms. of Charles Darwin, sketched in 1839, copied in 1844; (2) An abstract of the letter from Darwin to Gray (October, 1857); and (3) The essay by Wallace, written in February, 1858, "for the perusal of his friend and correspondent Mr. Darwin, and sent to him with the expressed wish that it should be forwarded to Sir Charles Lyell, if Mr. Darwin thought it sufficiently novel and interesting."

[11] Gray Correspondence, Gray Herbarium, Cambridge, Massachusetts.

[12] "Memoirs," American Academy of Arts and Sciences, New Series (Cambridge and Boston, 1859), VI, Part 1, 443.

Darwin's letter of September 5, 1857, of the genetic continuity of species.

Publication of the "Origin of Species" by Appleton

The confidence which impelled Charles Darwin to reveal his precious secret to Asa Gray readily explains why he should turn to him to supervise the publication of the "Origin of Species[13] in the United States. Darwin's first letter concerning this business was written after John Murray, of London, had brought out the first edition of the "Origin" in 1859. It tells of the remarkable sale of the entire edition on the first day, and of his ambition for an American edition.

> I should for several reasons be very glad of an American Edition; I have made up my mind to be much abused; but I think it of importance that my notions should be read by intelligent men, accustomed to scientific arguments though *not* naturalists. . . .
>
> The first Edition of 1250 copies was sold on the first day, and now my Publisher is printing off as *rapidly as possible* 3000 more copies. I mention this solely because it renders probable a remunerative sale in America. I should be infinitely obliged if you could aid an American Reprint, and could make, for my sake and Publishers, any arrangement for any profit.[14]

It might be well, at this point, to note the financial arrangement with Murray, which was generous and possibly suggestive: "My terms with Murray are that I receive ⅔ of Profits, & he ⅓."[15]

Asa Gray took steps to have the Boston publishers, Ticknor and Fields, bring out the "Origin of Species," as this letter to Darwin records:

> You have my hurried letter telling you of the arrival of the remainder of the sheets of the reprint; and of the stir I had made for a reprint in Boston. Well, all looked pretty well, when, lo, we found that a second New York publishing house had announced a reprint also! I wrote then to both New York publishers, asking them to give way to the *author* and his reprint of a revised edition. I got an answer from Harpers that they withdrew—from the Appletons that they had got the book *out* (and the next day I saw a copy); but that, 'if the work should have any considerable sale, we certainly shall be disposed to pay the author reasonably and liberally.'[16]

The subject of royalties is of interest to every author, and the custom of American publishers before the adoption of the international copyright law was that each paid as he saw fit. It has been maintained that American publishers treated English authors at that time the same as they did those of the United States. This widely accepted belief may be traced to the following statement of John Fiske: "The Appletons . . . always paying a royalty to the authors, the same as to American authors, in spite of the absence of an international copyright law."[17]

However, the following facts in reference to Darwin and Gray will show that Fiske's statement was not correct.

Darwin, writing to Asa Gray on May 22, 1860, said:

> Again I have to thank you for one of your very pleasant letters of May 7th, enclosing a very pleasant remittance of £22. I am in simple truth astonished at all the kind trouble you have taken for me. I return Appleton's account. For the chance of your wishing a formal acknowledgment I send one. If you have any further communication to the Appletons, pray express my acknowledgment for [their] generosity; for it is generosity in my opinion. I am not at all surprised at the sale diminishing; my extreme surprise is at the greatness of the sale. No doubt the public has been *shamefully* imposed on! for they bought the book thinking that it would be nice easy reading. I expect the sale to stop soon in England, yet Lyell wrote to me the other day that calling at Murray's he

[13] Publications of the "Origin of Species" by Appleton: 1860; New Edition, 1868; Fifth Edition, 1870; Sixth Edition, 1890; New Printing, 1892; Authorized Edition, 1896; New Printing, 1900; Sixth Edition, 1926.

[14] Gray Correspondence, Gray Herbarium. See, also, "Life and Letters," II, 39.

[15] Gray Correspondence, Gray Herbarium, Darwin to Gray, January 28 [1860].

[16] "Letters of Asa Gray," II, 456. See, also, "Life and Letters," II, 64–65.

[17] John Fiske, Edward Livingston Youmans (New York, 1894), 111.

heard that fifty copies had gone in the previous forty-eight hours.[18]

The following statement, mentioned in the above letter, was sent by Appleton to Gray; then forwarded to Darwin, who returned it to Gray:[19]

Asa Gray for Mr. Darwin.
DARWIN
Statement of the Sale of "Origin of Species" to May 1st, 1860.

On hand last account,		....
Printed Jan'y /60		1500
Feb'y /60		500
Mch /60		500
		2500
1750 Sold, at 5% on		$1.25
On hand this date,	250	
In hands of Booksellers,	300	550
Given away,		200
Sold to date,		1750
		2500
Copyright amounting to	$109.37	
	= £22.	00

A review of the Appleton-Gray correspondence at the Gray Herbarium showed that Gray received a royalty of 10 per cent. on the books they published for him over the period from 1877 to 1885.[20]

Darwin was eager for a second American edition, and that it should contain important corrections—especially about the "bear" story:

In the first edition one reads on page 184: 'In North America the black bear was seen by Hearne swimming for hours with widely open mouth, thus catching, like a whale, insects in the water. Even in so extreme a case as this, if a supply of insects were constant, and if better adapted competitors did not already exist in the country, I can see no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths, till a creature was produced as monstrous as a whale.' In a second edition the whole second sentence of this quotation was expunged, and in the first sentence a qualifying 'almost' was inserted after 'catching.'[21]

Appleton's attitude is revealed in this unpublished letter:[22]

NEW YORK, Feb. 17/60.

Prof. Asa Gray,
DEAR SIR:

Your favor of 15th is at hand. We can't say what we can do respecting the notes and additions till we see them but we shall be anxious to make our edition conform to any future English Edn.

You are under a mistake in supposing that new matter unpublished in England secures a copyright in this country if written by Mr. Darwin—on the contrary if the entire work had never been published in England and first appeared here no copyright would hold in this country as no one can hold a copyright here for what he has written unless he be a citizen of the U. S.

We proposed to ourselves to pay 5% on retail price as suggested in your letter, as there is no reason why a work without any legal rights, should pay the same as one that is secured by law.—We desire to act liberally altho' we printed the work after it had reached this country some little time; not having received even early sheets which is usual when any payments are made. We regret very much there is no protection to the foreign author, think it a monstrous shame, but we are obliged to take things as they actually exist.—We are quite willing if it would be agreeable to Mr. Darwin to send him a check for 50 £ Stg. and very likely that will be as much as he could receive by the sales.

We remain,
Very respectfully,
D. APPLETON & CO.

The following letters suggest that the Appleton Company were evidently annoyed with Darwin's requests for minor changes:

18 Gray Correspondence, Gray Herbarium. See, also, "Life and Letters," II, 104; and "Autobiography and Letters" (New York, 1893), 248.

19 Gray Correspondence, Gray Herbarium.

20 *Ibid.*

21 Paul B. Victorius, "A Sketch of the 'Origin of Species'": *The Colophon*, Original Series (New York, 1932). The writer has been given permission by Mr. Victorius to quote from this article.

22 Gray Herbarium, Cambridge, Massachusetts.

On May 7, 1866, Gray wrote Darwin regarding the new edition of the *Origin*, saying that he had heard nothing from the Appletons for years—"the sale, I suppose, has gone on slowly, but they have made no returns. . . . I will write to the Appletons asking them in the first instance if they will bring it out, and allow you the paltry 5% on sales; and if they decline I would arrange with a Boston publisher, and have the work brought out in a handsome form, as a standard author."

On July 3, of the same year, Gray again wrote to Darwin:

> I should have earlier replied to yours of 25 May. But the Appletons do not behave well. I wrote them on receiving your letter, June 9. They waited till 18th to reply, as enclosed. I wrote . . . urged the impracticability of altering the plates and your aversion to that, as that would be unjust to you—said we wanted now a neat and permanent library edition.—
>
> No reply to that. But yesterday I wrote saying I now had some sheets & asked . . . if they would object to my offering the sheets to some other publisher.
>
> I think it likely they will play *dog in the manger*—for which part they have advantages,—as they might reprint your additions & issue, with their old stereotype pages, without regard to appearance or decency, & so spoil the venture of any other publisher. At least the fear of it might deter any other publisher. We shall soon see if I do them injustice.

Gray, keeping Darwin posted as to publication developments, wrote to him twice during August, 1866—on the 7th and the 27th. In the first of these letters he said that "Appleton has, at my request, returned the sheets I had sent him. As he persisted in the idea of making what he called the *essential* alterations on his old stereotype plates, I thought that I could not for any petty pecuniary advantage, even connive at such doings." On the 27th, apparently disgusted with Appleton's methods, he wrote:

> I have yours of the 4th inst. . . . you rightly infer that there is no hope at present for an American reprint, unless you agree to fall in with Appleton's shabby ways—which I think you will not be tempted to do.
>
> But I am encouraged to think that I can make a *good arrangement* with Messrs. Ticknor & Fields, of Boston, to bring out the new book, & allow Author 12%. I shall confer with Mr. Fields.[23]

The review of the evidence in regard to the publishing of the "Origin of Species" by Appleton indicates that they paid Charles Darwin, through Asa Gray, 5 per cent. on the first edition, and *not* the usual 10 per cent. royalty, as Fiske stated. We have thus far been unable to locate any documented statements dealing with subsequent publications. However, there is the letter quoted above, from Appleton to Gray, and the postscript added by Gray, suggesting that there had been negotiations in reference to the publication of the second edition.

Asa Gray had forwarded Appleton's letter to Darwin, with this comment:

> Feb. 20, 1860.
>
> MY DEAR DARWIN:
>
> I got this to-day. I send Appletons, now, the sheets of ed. 2, and your additions appended in their places. I promise the Historical Preface next week, and I put it in their hands—trusting to their promise of 5 [prints] and to their honor for more if they are not molested by reprinters, which we shall keep off. . . . The offer of check for £50—(which I might send to Mrs. Darwin for pin-money, since you scorn it) tempts me,—but I think it wiser to wait and hope for more.[24]

At the close of a letter to Gray, written on September 25, 1860, Darwin added: "P.S.—Please observe that if the Appletons lose by the second Edition barely selling, I should PREFER repaying the money they have paid me."[25] Apparently the Appleton Company refused to make a definite contract; and here the evidence on what was paid Darwin as royalty on the "Origin of Species" closes.

This brief comparison of the first and

[23] These letters were copied from the originals at the Gray Herbarium.

[24] *Ibid.*

[25] *Ibid.*

second American editions lets the secret out, and confirms Gray's fears:

The second American edition was published during the summer of 1860. It appeared after the second and before the third English edition. This second American edition is of considerable bibliographic and scientific interest, because it contains matter never before published. The title-page describes it properly as 'A New Edition, Revised and Augmented by the Author.' The edition contains a preface here first published and a historical sketch. Although the second American edition was published at a sufficient interval after the second English edition to include all the corrections and alterations that appeared in the latter, one finds nevertheless the original bear story, which appears only in the first and not in the second English.[26]

We know that Darwin, as he had anticipated, was properly ridiculed and "much abused" for his "bear" story, which was carrying the influence of natural selection much too far. Of Harvey's criticism, he remarked that there would be: "no more difficulty than man has found in increasing the crop of the pigeon, by continued selection, until it is literally as big as the whole rest of the body."[27,28]

THE NORMAL BURNING OF GASEOUS EXPLOSIVE MIXTURES

II. ENGINE FLAMES, THEORIES AND APPLICATIONS

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Flames in Engine Cylinders

A text-book by Taylor and Taylor[31] on "The Internal Combustion Engine," published in 1938, includes a bibliography of about 540 references to reports bearing on engine operation. Of these at least one fifth are concerned primarily with the combustion process and the changes in this process which result when the operating conditions are varied. A brief review of such a broad field is necessarily limited to generalities. However, these may serve to illustrate the trends which past research on combustion in the engine cylinder has followed, as well as the complexity of the problem, and to some extent, the present state of our knowledge of the burning process.

It may not be amiss to enumerate, first, the principal sources from which published information on engine studies may now be expected. Very little material has appeared recently from the larger European countries, since all information pertaining to engines is considered of military importance. The one notable exception has been the research division of the Royal Dutch Shell Corporation. In this country the National Advisory Committee for Aeronautics sponsors a wide variety of combustion research at Langley Memorial Aeronautical Laboratory, at other government laboratories and at several universities. Some of our schools, such as Massachusetts Institute of Technology and Pennsylvania State College, are actively engaged in engine research. Many other universities have made contributions, and the list may reasonably be expected to increase rapidly under the stimulus

[31] C. F. Taylor and E. S. Taylor, "The Internal Combustion Engine," Scranton: International Text-book Company, 1938.

[26] Victorius, *The Colophon.*

[27] "More Letters of Charles Darwin," Francis Darwin, editor (New York, 1903), I, 162.

[28] The difficulties of obtaining a complete account of "How Darwinism came to the United States" are doubtless evident to the reader. Any corrections and additional facts will be welcomed by the author.

of the current nation-wide emphasis on aeronautics. Among the industries, there have been notable contributions from various producers of fuels and fuel dopes, and of aeronautic and automotive engines and accessories.

Studies of flame and combustion in the engine cylinder generally require that provision be made for observing both the rise in pressure during an explosion and the progress of the flame. As a result of the nature and behavior of our common motor fuels, engine studies are usually concerned, at least to some extent, with detonation or knock, which Boyd[32] has aptly called "the cancer of engine combustion." Since the very rapid burning during knock is accompanied by an exceedingly rapid rise in pressure, the occurrence of knock is clearly evident on both the pressure and the flame records.

A brief discussion of pressure indicators in general has been presented in a previous section. Those suitable for use in an engine cylinder must be sturdy to withstand the repeated shocks of continuous operation and must be adequately cooled. The design, theory and applications of a number of indicators which have been used with varying degrees of success are described in a book by De Juhasz[33] on "The Engine Indicator."

Flame travel in engine cylinders. The progress of the flame has been observed by using ionization gaps[34,35,36] or through windows which have varied in size from small ones giving very local views of the flame to cylinder heads made entirely of transparent material. Various stroboscopic devices, synchronized with the engine, have been used in conjunction with the windows to restrict the view to a small fraction of each cycle. In most cases, however, the travel of the flame has been recorded on a moving film, either continuously or in the usual frame by frame manner of the ordinary motion picture camera.

Recently special cameras, in which multiple lenses are rotated with the film, have been developed. One of these, described by Withrow and Rassweiler,[37] gives 5,000 photographs per second at an engine speed of 2,000 rpm. Stated in another way, this camera was used to take 30 separate photographs of the entire combustion chamber during the 72° of crank angle embracing the ignition and subsequent combustion of the charge.

Flame pictures of knockless combustion show that the progress of the flame from ignition to complete inflammation is continuous, and simultaneous pressure records are correspondingly smooth and free from any abrupt changes. Such records also show[38] that the flame speed increases almost as fast as engine speed and that the combustion process therefore transpires in roughly the same number of degrees of crank rotation, regardless of engine speed. A plausible interpretation seems to be that the amount of local turbulence in the charge is approximately proportional to engine speed. The more vigorous the mechanical stirring of the gases in the neighborhood of the flame front, the more rapid is the mixing of burned, burning and unburned particles, so that the opportu-

32 T. A. Boyd, *Soc. Automotive Engineers Jour.*, 45: 421–432, 1939.

33 K. J. De Juhasz, "The Engine Indicator," New York: Instruments Publishing Company, 1934.

34 K. Schnauffer, *Soc. Automotive Engineers Jour.*, 34: 17–24, 1934.

35 H. Rabezzana and S. Kalmar, *Automotive Industries*, 72: 324–329, 354–357 and 394–397, 1935; *ibid.*, 81: 534–542 and 632–639, 1939.

36 W. A. Mason and K. M. Brown, *Automotive Industries*, 72: 582–584, 1935.

37 G. M. Rassweiler and L. Withrow, *Indust. and Engineering Chem.*, 28: 672–677, 1936; L. Withrow and G. M. Rassweiler, *Soc. Automotive Engineers Jour.*, 39: 297–303, 1936.

38 C. F. Marvin, A. Wharton and C. H. Roeder, *Technical Report No. 556*, Nat. Advisory Committee for Aeronautics, 1936.

nity for fruitful collisions, and consequently the flame speeds, increase. For the same reason the turbulence which is always present in an engine cylinder is thought to account for the fact that, for comparable explosive mixtures the speed of flame in space is greater in the engine than in bombs.

Most flame photographs, and particularly those of the entire combustion chamber, show both the irregular pattern of the flame front produced by local turbulence and general deviations from symmetry of the whole flame, resulting from mass motions of the entire unburned charge as induced during the intake stroke.

The flame pictures taken after the flame has traversed the entire charge show the greatest luminosity in portions which were burned first. There thus appears to be a close relation between the intensity of the actinic light and the temperature of the burned gas, which has also been shown to be highest in the first part of the charge to burn.[39] Experimental proof of the existence of such a temperature gradient throughout the burned gas in a bomb was first given in 1906 by Hopkinson,[40] later demonstrated theoretically by Mache,[41] and evaluated quantitatively for the specific case of an ozone-oxygen explosion by Lewis and von Elbe.[42]

Correlation of flame and pressure records. Rassweiler, Withrow and Cornelius[43] have attempted to correlate high-speed motion pictures with simultaneous pressure records, giving special attention to the effects of changing the mixture ratio, spark position and throttle opening. This analysis leads to the conclusion that both the fraction of the volume and the fraction of the mass of charge which is inflamed at any instant can be computed from the pressure record alone, with an accuracy which is comparable with that of calculations based on combustion chamber dimensions and flame photographs.

Knocking combustion. In the case of combustion under knocking conditions, both the flame and the pressure records are similar to those under non-knocking conditions during the initial stages of the burning. Then, depending upon the composition of the explosive mixture and the operating conditions, there appears a sudden change in the nature of the flame photographs and in the pressure within the cylinder. Both these changes indicate an enormous increase in the rate of combustion, accompanied by vibratory motions within the gases, which, in turn, are transmitted to and through the walls of the combustion chamber and thence to the surrounding atmosphere in the form of audible sound waves, from which the knock derives its name.

The vibrations within the cylinder also cause vibration of the moving parts of the pressure indicator, so that the pressure records of a knocking combustion show, first, a sudden increase in the rate of pressure rise, followed by an interval of periodic fluctuations having gradually decreasing amplitudes. It has been shown[44] that the frequency of the waves in the flame photographs corresponds with the frequency of the vibrations on the pressure record. Further it has been shown that the frequency of the pressure waves within the cylinder is the same as the frequency of the audible

[39] G. M. Rassweiler and L. Withrow, *Soc. Automotive Engineers Jour.*, 36: 125–133, 1935.

[40] B. Hopkinson, *Proc. of the Royal Soc. of London*, A77: 387–413, 1906.

[41] H. Mache, "Die Physik der Verbrennungserscheinungen." Leipzig: Veit and Company, 1918.

[42] B. Lewis and G. von Elbe, *Jour. Chemical Physics*, 2: 537–546, 1934.

[43] G. M. Rassweiler, L. Withrow and W. Cornelius, *Soc. Automotive Engineers Jour.*, 46: 25–48, 1940.

[44] L. Withrow and G. M. Rassweiler, *Automobile Engineer*, 24: 281–284, 1934.

sound outside the engine.[45] The observed frequencies varied from 3,000 to 6,000 cycles per second, depending upon the dimensions of the combustion chamber and the temperature of the burned gas.

Because of the extreme rapidity of the burning after the knock has begun, only flame records taken at very high film speeds show that the subsequent inflammation of the charge does not take place simultaneously throughout all the remaining unburned gas. Withrow and Rassweiler[46] interpret their photographs to mean that auto-ignition occurs at a point ahead of and well separated from the flame, without much change in the form and position of the original, normal flame front. They conclude that "perhaps in all knocking explosions, the knock is definitely not a result of a sudden increase in the velocity of the advancing flame." From other original photographs, Rothrock and Spencer[47] are led to the belief that "although auto-ignition ahead of the flame front may occur in conjunction with severe knock, probably it is not necessary nor does it always occur with knock." The latter authors also see evidence in their pictures that reaction is not completed in the flame front and suggest that in some cases knock may occur in the burned gas as a result of the sudden liberation of the energy remaining after the initial passage of the flame.

Stansfield and Thole[48] suggest that three types of detonation may be possible, namely, true knock, auto-ignition, and pre-ignition, while Boerlage and his co-workers[49] distinguish between "pinking" and knocking. It is hoped that photographs of knocking combustion taken at still higher speeds may soon be available to answer some of the outstanding questions concerning the physical nature of the very rapid burning.

Radiation from engine flames. Other important information has been obtained by observations through windows opening into the combustion chamber. Among such studies may be mentioned various attempts to determine the radiation characteristics of both burned and unburned gas and the movements of the gases by schlieren photography.

In 1924, Midgley and McCarty[50] studied the relative effects of various operating conditions upon the total energy radiated from the combustion chamber through a quartz window and the slot of a timing stroboscope, by measuring the current output of a thermopile upon which the radiation was focused. The results for a given fuel showed that the mixture proportioned to give maximum power radiated the most energy, whether there was knock or not, and that, for a given piston position, energy was radiated at a greater rate during a knocking than a non-knocking combustion.

More detailed information concerning the mechanism of the processes in progress prior to the arrival of the flame and at all stages subsequent to the passage of the flame front has been obtained by studying both the absorption and emission spectra. Spectroscopes have been used in the ultra-violet and visible ranges, and the spectral distribution in the infrared was studied by the use of

[45] C. E. Grinstead, *Jour. Aeronautical Sciences*, 6: 412–417, 1939.

[46] G. M. Rassweiler and L. Withrow, *op. cit.* in reference 37.

[47] A. M. Rothrock and R. C. Spencer, *Technical Report No. 622*, Nat. Advisory Committee for Aeronautics, 1938.

[48] R. Stansfield and F. B. Thole, *Engineering*, 130: 468–470 and 512–514, 1930.

[49] G. D. Boerlage and W. J. D. van Dyck, *Jour. Royal Aeronautical Soc.*, 38: 953–986, 1934; G. D. Boerlage, J. J. Broeze, H. van Driel and L. A. Peletier, *Engineering*, 143: 254–255, 1937.

[50] T. Midgley and H. H. McCarty, *Soc. Automotive Engineers Jour.*, 14: 182–185, 1924.

appropriate filters. There is space for but a brief résumé of the conclusions from such studies.

Nearly all the energy radiated by the flame in an engine is in the infrared,[51] and apparently arises from the formation of H_2O and CO_2. In a normal combustion, radiation from these two compounds begins upon the arrival of the flame front and continues for some time thereafter, thus pointing to continued reaction. The duration of the continued reaction is much shorter when knock occurs. Although there is a great variation in the total energy radiated during a single cycle and under different operating conditions, the spectral distribution shows only small changes over a wide range of these conditions. The significance of the observed changes in distribution is not known.

The research groups of the General Motors Corporation have made valuable contributions[52] concerning both absorption and emission spectra. Among these reports the following conclusions may be found.

The absorption spectra of the unburned charge in that part of the combustion chamber where knock occurs show that formaldehyde is always present under knocking conditions. This compound is also found in the absence of knock, but its formation may be avoided by changing the operating conditions so as to reduce sufficiently the tendency to knock. The addition of tetraethyl lead does not affect the concentration of formaldehyde appreciably, while addition of enough aniline to suppress knock completely, decreases the formaldehyde concentration. The formaldehyde bands disappear when knock is stopped by increasing the concentration of fuel in the explosive mixture or by retarding the spark. Formaldehyde introduced with the intake air did not induce knock, even though a portion was shown to remain intact until the time of knock. Many other absorption bands are present prior to knock, but the molecules responsible for them have not been identified.

The emission spectra observed when hydrocarbons are burned either in a burner or in an engine cylinder show the characteristic bands of CH and C_2. However these bands are absent in the region behind the flame front, suggesting that the breakdown of the hydrocarbon is completed in the flame front. This does not necessarily mean, however, that the formation of H_2O and CO_2 proceeds to equilibrium in the front. Bands of OH radicals were found in the ultraviolet for both the flame front and the afterglow, and bands of HCO, while present in the front, are entirely absent in the afterglow.

In the knocking zone the intensity of the CH and C_2 bands was much lower in the knocking than in non-knocking explosions. Thus it is suggested that the hydrocarbon may be at least partly broken down by preflame reactions prior to the inception of knock. When tetraethyl lead was used to prevent knock, the intensity of the CH and C_2 bands increased, suggesting that the lead may inhibit preflame decomposition of the fuel.

Application of the spectral line reversal method of measuring the temperatures attained during explosions in the engine cylinder[53] shows that, after inflammation is complete, the temperature difference in the cylinder may exceed 300° C. When knock is present higher temperatures are reached earlier in the

[51] C. F. Marvin, F. R. Caldwell and S. Steele, *Technical Report No. 486*, National Advisory Committee for Aeronautics, 1934.

[52] L. Withrow and G. M. Rassweiler, *Indust. and Engineering Chem.*, 25: 923–931 and 1359–1366, 1933; *ibid.*, 26: 1256–1261, 1934.

[53] G. M. Rassweiler and L. Withrow, *op. cit.* in reference 39.

cycle, the subsequent rate of cooling is greater, and the exhaust temperatures are lower. It is of interest to note in passing that the maximum temperature observed in an engine with a compression ratio of only 4.4 : 1 exceeded 2,500° C., more than 1,000° C. above the melting point of the material constituting the combustion chamber.

Combustion in compression-ignition engines. Studies of combustion in the cylinders of compression-ignition engines are in general more complicated and not so far advanced as those in the more common spark-ignition type. The additional complications arise in connection with the injection of the fuel, its mixing with the previously compressed air and the auto-ignition of the resulting mixture.

Since ignition starts, not at a selected point, but in whatever place or places the necessary conditions of temperature and composition are first attained, the rate at which combustion proceeds must depend to a greater extent upon the state and distribution of the fuel than upon such characteristics of the mixture as transformation velocity and expansion ratio.

It is beyond the scope of this review to discuss the progress which has been made in studying the processes of fuel injection and mixing. This has already been done in Chapter 7 of "The Internal Combustion Engine,"[54] in which the original reports are also mentioned.

Other practical problems which must be solved to insure the satisfactory operation of a compression-ignition engine again involve control of the combustion process. Actually in this case control must be exercised over two closely related processes.

The first of these involves the delay period between the start of injection and the start of combustion, while the second involves the control of knocking after ignition has occurred. Since the delay period is not greatly affected by such factors as fineness of the fuel spray or the volatility of the fuel, but instead is largely dependent upon the temperature and pressure prevailing during the early part of the injection process, as well as upon the chemical characteristics of the fuel, it seems probable that during this period the fuel undergoes chemical changes producing materials which auto-ignite more readily than the original fuel. If the delay period is long there is greater chance for such materials to accumulate, so that auto-ignition may subsequently take place simultaneously at a great many places throughout the combustion chamber. Such conditions closely parallel those which exist in a spark-ignition engine just prior to knock. It therefore becomes apparent that a short delay period is of great importance if excessive rates of pressure rise are to be avoided.

The control of knock in compression-ignition engines is thus largely a question of controlling the delay period. This period, and also the tendency to knock, may be decreased by increasing the compression ratio, inlet air temperature, the initial pressure of the air in the cylinder (as by supercharging) and the temperature of the combustion chamber walls where the jet of fuel tends to impinge.

Theories of Flame Propagation

There have been numerous attempts to derive, from theoretical considerations, an equation by which transformation velocity can be calculated from known thermal properties of the burned and unburned mixtures. The earliest of these, proposed by Mallard and Le Chatelier,[55] was based on the primary assumption that heat from the flame was conducted to the ad-

[54] C. F. Taylor and E. S. Taylor, *op. cit.*

[55] F. E. Mallard and H. L. Le Chatelier, *Annales des Mines,* 4: 274, 1883.

jacent unburned gas until its temperature was raised to the "ignition temperature," when it in turn became inflamed. Subsequently this theory was modified and extended by Jouguet,[56] Nusselt,[57] Daniell,[58] and others, each treatment retaining the assumption that the gas to be burned must be first raised to its "ignition temperature" by direct conduction of heat from the flame.

More recently Lewis and von Elbe[59] proposed that "flame propagation is governed by diffusion of active atoms and radicals into the unburned mixture, which gives rise to chemical reaction there in a far more efficient way than would be possible purely by heat transfer." The working hypothesis of this theory is that "the sum of the thermal and chemical energy per unit mass in any elementary layer between the unburned and burned phases remains sensibly constant." A solution of the problem along these more complicated lines, involving both reaction kinetics and heat transfer, is at present possible only when other daring approximations are made. Such a solution has been made for the particular case of explosions in ozone-oxygen mixtures, where the calculated values of transformation velocity are of the same order of magnitude as the experimental values. In addition the analysis provides information as to the structure of the reaction zone, that is as to the gradients of temperature, concentration, and reaction rate. The calculated thickness of the reaction zone is of the order 10^{-3} to 10^{-4} cm.

[56] E. Jouguet, *Comptes Rendus*, 156: 872–875, 1913; *ibid.*, 168: 820–822, 1919; *ibid.*, 179: 454–457, 1924.

[57] W. Nusselt, *Zeitschrift des Vereines Deutsches Ingenieure*, 59: 872–878, 1915.

[58] P. J. Daniell, *Proc. Royal Soc. of London*, A126: 393–405, 1930.

[59] B. Lewis and G. von Elbe, "Combustion Flames and Explosions of Gases," pp. 211–219. London: Cambridge University Press, 1938.

None of the theoretical treatments of flame propagation may be considered adequate for the calculation of usable values of transformation velocity. This is not surprising in a problem of such complexity, since some of the complicating features may not yet have been discovered and since others are poorly understood. As examples, the kinetics of the reactions are in many cases obscure, and the question of the continued evolution of energy within the flame front is still in dispute.

In addition to the above mentioned attempts to derive theoretical expressions for transformation velocity, there have been efforts to formulate certain "laws of flame speeds" of an empirical nature, based on available experimental data. Among these may be mentioned the suggestions of Payman and Wheeler[60] and of Stevens.[61] The former stated that "given two or more mixtures of air or oxygen with different individual gases, in each of which the speed of propagation is the same, all combinations of mixtures of the same type, that is all containing excess of oxygen, or all containing excess of combustible gas, propagate flame at the same speeds, under the same conditions of experiment." In later interpretations the proponents of this "law" elaborated upon it by stating that "any addition of incombustible gas, inflammable gas or oxygen to a mixture of inflammable gas and oxygen in combining proportions has a retarding effect upon the speed of uniform movement of flame proportional to its specific heat" and that "the time taken for pressure within a spherical vessel to attain its maximum . . . coincides with the time taken for flame to reach the boundary of the vessel, except in very slowly moving flames."

[60] W. Payman and R. V. Wheeler, *Transactions* of the Chemical Society, 121: 363–379, 1923.

[61] F. W. Stevens, *Technical Report No. 176*, Nat. Advisory Committee for Aeronautics, 1923.

Bone and Townend[62] object that the "law" and its corollaries imply that combustion is complete in the flame front and that either dissociation does not affect flame speed or that the degree of dissociation is unaffected by dilution with inert gas or excess of one reactant. They present data for mixtures of hydrocarbons, hydrogen and oxygen which appear to deviate from the "law" and state that "whatever measure of truth there may be in Payman and Wheeler's conclusions in regard to particular instances, they are not generally applicable to gaseous explosions, and therefore can not be vested with the authority of a natural law."

As a result of all of his work with gaseous explosions Stevens concluded that, within the limits of his experimental error, the transformation velocity was directly proportional to the mass action product of the active constituents in the original mixture. More recent determinations by the bubble method,[63] yielding values of S_t believed to be of higher accuracy, show much larger departures from this relation than did the results of Stevens. It therefore appears that the relation is an approximation which fails to take account of at least some of the factors which influence transformation velocity. One of its most apparent shortcomings is that it yields a maximum value of S_t at exact chemical equivalence, while the observed maximum always occurs in the presence of some excess of fuel.

A great many experimental studies have been made of the molecular kinetics of reactions between gaseous fuels and oxygen. Many of the results of such studies may be explained on the basis of the theory of chain reactions. A chain reaction is one in which one kind of active atom or radical, called a chain carrier, effects the formation of a large number of product molecules due to its regeneration. Thus the complete picture on a molecular scale of the reaction of fuel and oxygen can be represented in detail only by a group of chemical equations, many of which yield products which are so active and so short lived that they are not found at all in the final products of the reaction, and therefore do not need to appear in the stoichiometric equation representing the overall reaction.

The progress which has been made with the chain theory of reactions is reviewed by Lewis and von Elbe[64] in the first four chapters of their book. Such treatment deals largely with specific instances, which are too numerous to recount here. Despite the fact that real progress has been made, it seems at present that much additional evidence is needed to establish a comprehensive picture of oxidation on a molecular scale.

It is hoped that the present lack of generally applicable postulates concerning the mechanism and rate of gaseous explosive reactions has been sufficiently emphasized in the material which has been preesnted. Such a situation has doubtless hampered, but by no means prevented progress in technical applications of the combustion process.

Some Technical Applications of Combustion Research

Most of the applications of combustion research have been referred to, either directly or by implication, in previous sections of this report. One important group of these is concerned with the prevention of unwanted explosions, with a view to the reduction of accidental hazards in mines and in industry.

[62] W. A. Bone and D. T. A. Townend, "Flame and Combustion in Gases," London: Longmans, Green and Company, 1927.

[63] E. F. Fiock and C. H. Roeder, *Technical Report No. 532*, Nat. Advisory Committee for Aeronautics, 1935.

[64] B. Lewis and G. von Elbe, *op. cit.* in reference 59.

Other general applications of gaseous explosive reactions occur in domestic and industrial heating devices and in internal-combustion engines.

Since the earliest progress was made in the field of safety, it is logical to begin with the applications in this field. Probably the surest way to prevent an explosion is to so control the concentration of fuel in the atmosphere that the resulting mixture never becomes combustible. A first step in such a process is obviously the determination of the limits of flammability. Once these and the possible rates of formation of gaseous fuel are known, it is usually a routine problem for the ventilation engineer to avoid the formation of a combustible mixture.

In many instances, such as arise in the handling and storage of flammable liquids, it is not practicable to avoid at all times the formation of explosive mixtures. It then becomes desirable to reduce the chance of accidental ignition to a minimum. That this effort has not always been successful is illustrated by such well known disasters as those which destroyed the stratosphere balloon Explorer I, and the Zeppelin Hindenburg, and that which recently damaged an oil tanker in dock on the east coast.

The invention of the Davy safety lamp has already been mentioned. By merely inserting a wire gauze between the flame of the lamp and the explosive mixture which often occurred in poorly ventilated mines, this device in effect removed an ever-present source of ignition. It is of course impossible to make any reasonable estimate of the number of mine explosions which have been averted by the use of the safety lamp, or of the number of lives which would have been lost without it.

Flame traps of various sorts, operating on the same general principle as the safety lamp, have been used to prevent the travel of flame along pipes and tubes which convey explosive mixtures or which might accidentally become filled with such mixtures.

In the absence of all external sources of ignition, it is also important to know whether or not there is a possibility of spontaneous ignition in the vapor phase adjacent to a flammable liquid. Therefore many attempts have been made to determine, experimentally, the lowest temperatures at which such mixtures will burst into flame. However, as previously stated, the experimental methods have been more satisfactory for comparative than for absolute results. It may be that in both the experimental and practical cases some such factor as surface condition may be of controlling importance, and that an explosion in a particular tank might result from spontaneous ignition when the temperature of the surroundings was lower than any which had produced ignition of the same explosive mixture in other containers.

The large number of applications of gaseous explosive reactions for the direct production of heat are so familiar that enumeration would be entirely superfluous. The problems involved are those of the stationary flame. More specifically these problems are concerned with the relation of flame and burner, that is with the matching of the flame and burner to the requirements of the application.

Diffusion flames, in which the rate of liberation of energy is limited by the speed of mixing of the fuel and oxygen, produce less heat per unit area than Bunsen-type flames consuming fuel at the same rate. Flame speeds play such a minor part in determining the shape and behavior of the diffusion flame that they need scarcely be considered in connection with such flames.

On the other hand, in burners in which the fuel and oxygen or air are pre-mixed, the transformation velocity is of primary importance, since it fixes the limits over which the rate of flow

of the explosive mixture through a given port can be varied without blow off or flash back. Most appliances using gas flames provide for variation in the ratio of fuel to oxygen as well as in the velocity of the mixture. Since transformation velocity decreases as the composition is varied in either direction from the optimum, the limits of stable operation are rapidly narrowed by such changes in the mixture ratio. Thus knowledge of the transformation velocity and its variation with composition is highly desirable in any attempt at burner design.

A more complete discussion of the problems of stationary flames has been presented by Smith,[65] and further elaboration is not necessary here.

The application of the gaseous explosive reaction as a source of power in internal combustion engines has had the most profound effect upon the life of every one, particularly in this country. Past, as well as future efforts have been and logically should be concentrated upon more efficient control and use of the combustion process. At present there is considerable emphasis on the search for new fuels having less tendency to knock than those commonly available.

[65] F. A. Smith, *Chem. Reviews*, 21: 389–412, 1937.

Conclusion

From what has been presented, it is probably apparent that a vast amount of painstaking research has been done in the field of combustion. Yet it may truthfully be said that not a great deal is actually known of the highly complex mechanism, on a molecular scale, by which the chemical energy latent in the fuel is converted into usable mechanical energy. This does not mean, however, that past efforts have been futile, or that small progress has been made. Rather, it seems to indicate either that no mind capable of fitting the great number of isolated bits of information together to form a comprehensive whole has yet appeared, or that some important factors have so far been overlooked entirely.

OBSERVATION AND EXPERIMENT

Of the infinite variety of phenomena which appeal to our senses, some, like those of sidereal astronomy, are subject, in the main, to observation only; while others, like those of terrestrial physics, chemistry and biology, are subject to both observation and experiment. All phenomena are more or less entangled. They point backward and forward in time; any one of them appears and disappears only in connection with others; and the record any one of them leaves is known only by its interaction with others. Out of this plexus of relations and interrelations it is the business of science to discover the conditions of occurrence and the laws of continuity. Happily for man, although the ultimate complexity of phenomena is everywhere very great, it is frequently possible to trace out these laws. But the results we reach are essentially first approximations, depending, in general, on the extent to which we may ignore other phenomena than those specially considered. In fact, a first step towards the solution of a problem in science consists in determining how much of the universe may be safely left out of account. Thus the method of approximating to a knowledge of the laws of nature is somewhat like the method of infinite series so much used by mathematicians in numerical calculations; and as it is a condition of success in the use of such series that they be convergent rather than divergent, so is it an essential of scientific sanity that the mind be restricted by observed facts rather than diverted by pleasing fancies.—*Professor R. S. Woodward, president of the American Association for the Advancement of Science, speaking before the New York Academy of Sciences, February 25, 1901.*

INHERITANCE OF MENTAL DEFECT

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MENTAL abnormalities in man are conveniently divided into two classes, defect and disorder. The distinction between lunacy and idiocy, though not entirely free from theoretical difficulty, is of great practical value and has been recognized since medieval times. An idiot is a person in whom mental powers are so impaired from birth or an early age that he never is able to take his place as a member of ordinary society. He is not capable of learning the necessary reaction patterns even to defend himself against common dangers. This situation is different entirely from that of a person who, for many years, participates in the normal life of the community but who breaks down in health and becomes incapacitated mentally. Notwithstanding, the mental level reached in severe chronic cases of mental disorder sometimes approximates to the level of idiocy.

The exact definition of what constitutes mental defect in the modern sense is made difficult by disagreements in terminology but, for general purposes, it is possible to speak of two main groups. The low grade, or severe cases, include those who are ineducable or only partially educable by special training and who are now known as idiots and imbeciles. Within these limits imbeciles are, by definition, more intelligent than idiots. The incidence of severe defect in the general population is estimated to be not less than one in four hundred. The high grade, or mild cases, are those who are educable, but lag behind the rest of the class at school. This group is considered to comprise about one per cent. of the general population and is made up of morons and "borderline" cases.

There are medical, sociological and biological reasons for the separation of severe and mild cases. The upper limit of the high-grade group merges into the general population; physically, most morons are not distinguishable from the normal, though some are short in stature and subnormal in head size. The majority of them live their whole lives without being noticed as unusual. Those who are poorly adjusted or who, in addition to defect, suffer from mental disorder generally become social failures in childhood, adolescence or later and require institutional training and care. From the biological point of view morons are quite well fitted to survive, provided their surroundings do not require the exercise of fine degrees of discrimination. They are able to produce families, or as some eugenists have expressed it, they can "proliferate"—people more generously endowed with ability and self-esteem are said to "breed." The low-grade cases are, on the other hand, almost completely infertile; at an early age it becomes obvious that they can not take part in the ordinary life of the community. They lack all initiative, and are very often physically malformed and unattractive to the casual observer. Their infertility is, for the most part, due to their incapacity to find a mate. While discussing this aspect of the subject it is well to point out that the fertility of high-grade defectives is often restricted probably for the same reasons —lack of initiative and unattractiveness. The solution found by some of them is to unite with one another, often without regard for the niceties of prevalent codes of morals. In this way clans have been founded in which the lack of intelligence coupled with fertility has attracted much

attention from sociologists. Enthusiasm for schemes directed towards eliminating such groups as these from the population is now not as great as it was a decade ago. The schemes for sterilizing a few selected cases or even all certified cases can not be expected to cause an appreciable reduction in the magnitude of the social problems due to the existence of these sub-cultural clans, at least within a century or two. People in several countries are now wondering whether before that time the defectives (and every one else) may not have been exterminated by bombs; alternatively, they hope that their defectives will survive so that as many of them as possible can be trained to supplement their man power. Nevertheless, it is a matter of great interest to medical science to know how mentally defective individuals of all kinds originate.

Adverse factors in the environment, which operate at any time after a child is born, are responsible for mental impairment in a certain number of cases. Some of these environmental factors are more often operative in the high-grade and others in the low-grade group. They must be appreciated before the hereditary factors can be intelligently discussed. If injury or disease affects the brain of an infant so that its subsequent development is impaired, defect may result but, in the opinion of most observers, no great proportion of the total number of cases of mental defect can be attributed to such accidents. A few cases of defect, usually severe, and associated with paralysis of one side or other of the body, are undoubtedly due to injury at birth. It is, however, incorrect to assume that injury at birth is a major factor in the production of mental deficiency. On the other hand, there is evidence that in the period before birth environment is by no means constant for every child, though detailed knowledge of the means whereby intra-uterine influences affect mental development is limited. In medicine it has been usual to speak of lues (syphilis) as capable of hereditary transmission but this, of course, is a misuse of terms. The infection can be transmitted from mother to child before the child's birth, and in this way damage may be caused to the brain of the child, sufficient to impair seriously its subsequent mental capacity. It has been estimated that from 1 to 5 per cent. of institutional cases of mental defect are, at least partly, due to congenital lues.

A somewhat more frequent group of cases also owes its origin in a large measure to prenatal environment but in quite a different way. These patients are called "mongols" because Langdon Down, who first drew attention to the group, thought that they resembled Chinese children. Actually such cases have been distinguished among Asiatic populations and in almost every country in the world. The appearance of slanting eyes, which these children sometimes show, is only one of a great number of characters which, when taken together, indicate a retardation of development, both of the brain and the rest of the body, at any early foetal stage. The most important factor in the origin of the "mongol" type of imbecile is associated with the age of the mother at the time of pregnancy. The affected child is often found to be the last born in a large family, but the cause is not dependent upon maternal exhaustion through too frequent child bearing—it depends upon maternal age alone. The risk of a woman's giving birth to a "mongol" child is approximately doubled every five years after she reaches the age of 25. Half the cases are born to mothers who are more than 37 years of age. The father's age does not seem to matter at all. There are also other abnormalities of development of the nervous system in which the cause is associated with the

age of the mother though in a lesser degree than is the case in mongolism. In some of these conditions the chance of the first-born child's being abnormal is slightly greater than the chance of abnormality in the children born afterwards to the same parents. Recently the investigations of Murphy have also shown that therapeutic doses of x-rays given to a mother during pregnancy increase the risk of her giving birth to a malformed child.

The external influences which are significant in the severely affected group belong to the field of medicine. The influences of social environment, however, are significant in relation to the mild cases. Intelligence probably can not be altered by education, but certifiability and necessity for institutionalization depend very much upon training. The high-grade cases—the morons—are abnormal chiefly because they are unable to be good citizens. Those of the worst characters and habits are the most likely to be certified. Scarcely one tenth of the number of morons who actually exist in the population are to be found in institutions, even in those communities where mental health is most assiduously looked after. Intelligence, like stature, is graded and there is not a natural cleft between the normal intelligent person and the moron; consequently, the line between the two has to be drawn arbitrarily. Its position depends upon a delicate balance between individual ability and the reaction of the individual to the demands of the social environment in which he finds himself.

The true hereditary factors which cause mental defect are determined at conception, and their effects become manifest at any time during the early life of the individual. The family history in cases of severe defect usually differs in a number of ways from the family history in the mild cases because the hereditary mechanisms which act in the two types of cases are probably different. It will be convenient first to discuss the low-grade cases. Here the parents are, as a rule, normal physically and mentally; so, also, are the majority of the patients' brothers and sisters. Occasionally two or more idiots or imbeciles are born to normal parents, but this is exceptional. If one child affected in this way has been born, and if the parents are both normal, the chance that another child will be affected is less than 3 per cent.[1] This prognostication presupposes that the exact nature of this defect is unknown, for there are a number of specific diseases which cause low-grade defect and which behave as Mendelian recessive characters. If a recessive condition is diagnosed, the chance, that brothers and sisters of the affected child will suffer from the same condition, is 25 per cent. in the usual case, where the parents are both unaffected.

Some of the recessive diseases which cause imbecility or idiocy are of great medical and biological interest to those people who are lucky enough not to be affected themselves. Two forms are known of a progressive, degenerative condition which causes children, though at birth they appear healthy, to become blind and paralyzed idiots either in infancy or during school age. These illnesses are, fortunately, extremely uncommon. The infantile form is practically only found in Jewish populations. Naturally, no affected person ever has children of his own. The family history often shows the characteristic picture of a rare recessive disease, *i.e.*, parents normal, and related to one another by consanguinity, with one or more affected children and also some perfectly normal children. Another very interesting recessive disease, which causes gross mental retardation, but which is not progressive, was identified in Norway a few

[1] *Eugenics Review*, p. 35, 1939.

years ago by a biochemist, Fölling. He found that a substance, phenylpyruvic acid, was always present in the urines of certain imbeciles; in the normal person this substance is not excreted at all, possibly because it is utilized in the functioning of the brain. The disease seems to be more widely spread in Norway than in some other countries, though cases have been described in England, Scotland and France. In the United States many cases have been found, but only a small number of them have Norwegian ancestry. Other important recessively determined types of mental defect are associated with symmetrical paralysis of both sides of the body from birth or any early age. These cases of "cerebral diplegia," or Little's disease, are sometimes ascribed erroneously to birth injury. Normally the condition is not progressive. There is a variety of types, and it is certain that some of them are recessive characters. There are also many more conditions inherited in the same way and often associated with severe mental impairment. Among these are some types of cretinism, deafmutism, congenital eye defects and extreme underdevelopment of the brain (microcephaly). Cases of severe mental defect, which are genetic in origin and yet are not due to recessive factors, form another group. Their occurrence is, for the most part, sporadic; that is to say, they occur unexpectedly in normal families. One curious disease, in which the brain is malformed in a manner which, according to the pathologists, resembles potato roots (tuberose sclerosis) and in which tumors develop on the skin and in other parts of the body, often causes severe mental impairment and epilepsy. A fairly large proportion of these cases is sporadic. In some instances, however, usually when the patient is not severely affected, another member of the family, perhaps a parent, suffers from the same condition. The explanation is probably that tuberose sclerosis is due to a single dominant gene mutation. The assortment of abnormal characters produced by a fresh mutation of this gene gives rise to a condition so serious that an affected person is unlikely to have any children and, thus, does not usually transmit the abnormalities to the next generation. From a knowledge of the frequency of occurrence of cases of defects due to fresh mutation, the mutation rates of certain genes in man have been estimated. If the length of life of man, as compared with that of the fly, is taken into consideration, the mutation rate is found to be of the same order of magnitude in both species.[2]

An important group of low-grade cases, which already has been referred to, includes the mongolian imbeciles and a large variety of severe types of congenital malformation. The significance of maternal age in relation to these conditions, has already been mentioned; probably this association denotes a contributory cause which enables an underlying disposition to become manifest. The nature of the underlying disposition can, at present, only be surmised. The experimental work of Snell and others, on malformations of the nervous system in mice, suggests that in those animals derangement of the normal chromosome pattern may be a cause of such defects. The same kinds of peculiarities quite conceivably can occur in chromosomes of man. They might be expected to cause severe abnormalities with familial incidence so slight that the majority of cases would appear sporadically.

In order to complete the description of the genetical factors underlying severe mental defect, attention should be drawn to a few diseases which are sometimes associated with it and which are due to sex-linked or partially sex-linked genes. These include some of the my-

[2] *Nature*, 135: 907, 1935.

opathies (progressive muscular degeneration) and some eye diseases. On the whole, sex-linked inheritance seems to play a comparatively small part in determining intellectual subnormality. Sufficient has been said to show that the hereditary background of the low-grade cases is complex and varied. Recessive factors play an important part, but the hypothesis, favored by Goddard in his pioneer work on this subject, that all heritable mental defect is a single recessive trait, is untenable.

When the family histories are investigated in cases of mild defect—the morons, the simpletons, the weak-minded or whatever designation is preferred—a different picture is obtained. An appreciable number of the parents are found to be of mental caliber no greater than that of the offspring studied. The proportion of defective parents is estimated by various observers to be from 15 to 50 per cent., according to the position of the arbitrary standard set for defining what constitutes the lower limit of normal intelligence. Since the major part of the group of mild cases is only arbitrarily distinguished from the normal, the laws which govern the inheritance of intelligence in the normal group are likely also to hold for the subnormal or "subcultural" group (as Lewis termed it). According to what is known at present, intelligence—in so far as it is an innate quality—is determined by a large number of hereditary factors, some dominant, some recessive and some cumulative in action. The general rule which covers multifactorial inheritance of this kind is that the average intensity of the quality so determined will be the same in the children as it is in the parents. That is to say, the combined intelligence rating of the parents sets the standard rating for their children, some of whom, however, will possess ability above and some below this level. If, in addition to subcultural mentality a particular patient should have the misfortune to suffer from a mental disorder, such as epilepsy or schizophrenia, the genetic causation of the disorder must be analyzed separately to give an accurate picture of the hereditary background of the case.

In conclusion, it is of some interest to speculate upon the possible value and limitations of eugenic proposals for eliminating mental defect by selective sterilization. Since the severe cases are mostly infertile the eugenic attack must be made on potential parents of imbeciles and idiots. This will involve the sterilization of the carriers of defects, who will themselves be healthy in nearly every instance. At present these normal carriers, though they are known to be much more frequent in the general population than are imbeciles and idiots, can not be identified with certainty until they are already the parents of at least one abnormal child. The attempt to eliminate recessive or sporadic conditions from the population by eugenic sterilization will be a thankless task to say the least. Natural selection has failed to do this in thousands of years.

The attempt to eliminate mild cases by eugenic measures encounters other difficulties. It would be theoretically possible to diminish the incidence of high-grade defect in a sensible degree by sterilizing every person whose mental ability fell short of some specified margin. The problem of how best to define this margin efficiently has, however, not been solved. If the margin is low, the results of the efforts are ineffective. If, on the other hand, the margin is set high enough to be really effective, it would mean that about a tenth of the population might have to be prevented from having children. At the present time, when numerically large populations are considered to be desirable, no such proposals as these would meet with general

approval. Some authorities have given publicity to the belief that, in most civilized countries, the average degree of intelligence is declining because the morons have the highest reproduction rate in the community. If this is true, to sterilize the most fertile group would be suicidal. More probably it is not true. The highest fertility in the community perhaps does not rest with the most highly cultured groups, but it is probably associated with a degree of intelligence which, if not one hundred per cent., is only just below the average level —well within the range of what is considered to be normal ability. It would indeed be rash, in this fluctuating world, to lay down hard-and-fast principles about what human beings were most suitable to survive in the long run. A high general level of intellectual ability is probably necessary for the satisfactory development of civilization, but the most biologically efficient human beings can not be classified on the basis of intelligence alone.

DISEASE DAMAGE IN GRAINS

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In a nation which has already become accustomed to some form of crop acreage control and in which experiments in crop insurance are being conducted, information regarding crop losses due to disease is of importance to thoughtful citizens. It is the purpose of this article to present the available evidence on this subject as it relates to our basic food crops, the grains.

Two sets of disease loss estimates derived from quite different sources have been published by the United States Department of Agriculture. For the years 1909 to 1925, inclusive, the percentage of damage caused in various crops was compiled from estimates sent in by thousands of crop reporters in all parts of the United States. The estimated annual reduction for these years, together with the average for the years 1916–1925, was published on pages 321–322 of Volume 3, Supplement Number 10, "Crops and Markets." Apparently no figures of this type were published after 1925. The averages for the decade 1916–1925, which are slightly higher than for the earlier years, but fall in the same order, are in percentage: wheat, 5.2; oats, 2.8; barley, 2.7; corn, 0.4. Rye is not mentioned.

The order in which the various grains fall in this list seems to agree with the general impression among informed agronomists. Wallace and Bressman[1] say (page 139) "Corn is freer from disease damage than most other crops." Moreover, in a series of articles discussing progress and possibilities in plant and animal breeding, prepared by specialists of experience and high standing in their respective fields and published in the United States Department of Agriculture Yearbooks for 1936 and 1937, relatively much more space was given to discussing disease resistance in wheat, oats and barley than in corn. The relative amounts expressed as percentage of total space which was given to this phase were: wheat, 11.5; oats, 10.5; barley, 7.0; corn, 1.9.

Beginning in 1917 and continuing to the present time, the Plant Disease Survey has assembled and published esti-

[1] H. A. Wallace and E. N. Bressman, "Corn and Corn Growing," fourth edition. New York. 1937.

mates of crop losses sent in by collaborators, professional pathologists, in the various states. These figures are estimates in the true sense of the word, and no pretense is made that they represent a high degree of numerical accuracy. They are, however, the best obtainable and certainly should be considered in any attempt to evaluate the losses caused by plant disease in the United States. These estimates of losses due to disease in the four small grains for the period 1917–1937 are given in Figs. 1 and 2. Certain correlations between these figures and those derived from the estimates of the crop reporters are at once apparent. Throughout the period, the losses in rye, not mentioned at all in the other list, are smaller and fluctuate less than those of the other grains. Losses in wheat on the other hand are estimated as being higher and fluctuating more than those of any other small grain. The most striking contrast is, of course, between wheat and rye.

As regards disease losses in corn, the agreement between the estimates compiled by the Plant Disease Survey and the figures obtained by the other method is less evident. The disease estimates for the two most important grain crops, wheat and corn, may be directly compared in Fig. 3.

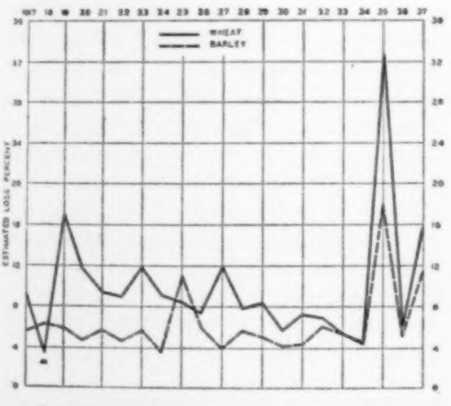

FIG. 1. ESTIMATED LOSSES FROM ALL DISEASES OF WHEAT AND BARLEY IN THE UNITED STATES (REPORTING AREA) 1917–1937.

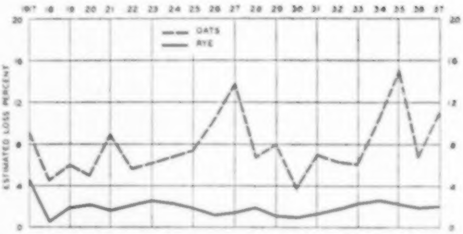

FIG. 2. ESTIMATED LOSSES FROM ALL DISEASES OF OATS AND RYE IN THE UNITED STATES (REPORTING AREA) 1917–1937.

In the loss estimate figures derived from reports of the crop reporters, corn appears at the bottom (0.4 per cent.), wheat at the top (5.2 per cent.), whereas in the figures compiled from reports of the collaborators of the Plant Disease Survey, the *average* losses in wheat and corn for the twenty-year period are approximately the same: 9.86 for wheat and 9.74 for corn. A possible explanation of the difference may be found in the different points of view from which the estimates were made. It seems entirely reasonable that considerations of economic importance of disease, rather than of total losses, greatly influenced the estimates of the crop reporters, many of whom were growers, or were commercially interested in crop production.

Among the factors which go to determine the economic importance of a disease, total average loss is only one item, and perhaps far from the most important item. In any list of factors to be considered in determining the economic importance of a disease, the extent to which the losses it causes fluctuate from year to year must occupy a place. Under present economic conditions, at least, fluctuations in losses are no doubt more important than total losses. Equally certain is the fact that large fluctuations must be very much more important than small ones. The extreme case is of a fluctuation so great as to produce actual famine conditions which would be *infinitely* more important than smaller ones. The difference between wheat and corn

in this respect is clearly shown in Table 1, in which, indeed, the relative positions of all the grains show a striking correlation with their positions in the list derived from the estimates of the crop reporters.

TABLE 1

FLUCTUATIONS IN CROP LOSS ESTIMATES COMPILED BY PLANT DISEASE SURVEY. NUMBER OF YEARS 1917–1937 SHOWING THE INDICATED DIFFERENCES FROM THE PRECEDING YEAR

	2 Per Cent. or Less	2–4 Per Cent.	4–8 Per Cent.	8–16 Per Cent.	Over 16 Per Cent.
Wheat ..	8	4	4	2	2
Barley ..	14	1	3	2	.
Oats ...	8	5	6	1	.
Corn ...	10	5	5	.	.
Rye	19	1	.	.	.

It would appear from these figures that the stability of yield of corn has been much less affected by disease than has that of wheat. The contrast between our two great cereal crops as regards *dependability* is recognized in the Agricultural Adjustment Act of 1938.

The corn acreage allotment was calculated to produce, including the entire crop and carry-over, a total supply equal to 110 per cent. of a normal year's domestic consumption and exports. The wheat acreage allotment was calculated to produce with the carry-over not less than 130 per cent. of a year's normal domestic consumption and export requirement.

Likewise, marketing quotas for the commercial corn-producing area were to be announced for the following year, subject to a referendum, if the total supply was estimated at more than 10 per cent. above the normal supply. Marketing quotas for wheat, on the other hand, were to be proclaimed only if this supply should exceed by as much as 35 per cent. a normal year's domestic consumption and export requirements.

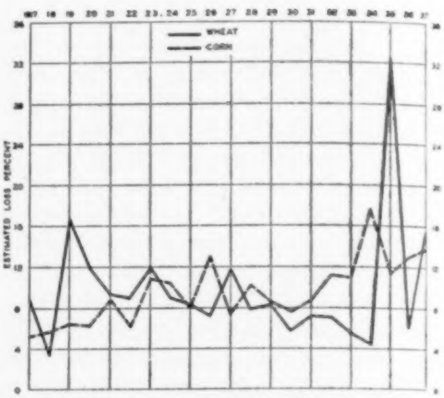

FIG. 3. ESTIMATED LOSSES FROM ALL DISEASES OF WHEAT AND CORN IN THE UNITED STATES (REPORTING AREA) 1917–1937.

Of course, factors other than fluctuations in size of crop enter into these figures. Also, factors other than disease help cause these wide fluctuations, but as stated on page 115 of the report on agricultural adjustment for 1937–38, the wheat farmer faces two chronic dangers —the risk of crop failure and the danger of tremendous surplus. If crop failures due to rust epidemics could be eliminated, it would be easier to guard against the surpluses.

Secretary Wallace has said, "Fluctuations in yields cause as much embarrassment as unbalanced acreage."[2] An important part of the work of American plant pathologists would seem to be to reduce the *fluctuations* in plant diseases. Most attention may well be given then to those food crops in which the losses from disease show the greatest fluctuations. A survey[3] of the literature of plant diseases during the past half century or more indicates that this has been the case.

[2] *New Republic*, December 2, 1936.

[3] Neil E. Stevens, SCIENCE, 89: 339–340. 1939.

THE HIGHER EDUCATION: CONTROLLED OR UNCONTROLLED?

By Dr. CHARLES A. DRAKE

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In the Pennsylvania Study[1] it is reported that students showed measured gains as great or greater in some subject-matter fields not part of their curricula as they showed in the subject-matters upon which they were ostensibly concentrating. Whence come such gains? Are the courses in professionalized subject-matters so enriched in the teaching process that they yield striking gains in fields only remotely related to them?

When the students in the last two years of an engineering curriculum are reported as making gains in fine arts, in foreign literature and in English literature as extensive as the gains shown in science and mathematics, what are we to infer? Does the engineering curriculum in its later years operate in a cultural environment of singular richness? Do the instructors go far afield in providing a background of unexpected breadth? Or are teachers taking credit—and blame—for phenomena over which they have little or no control?

Without in the least disparaging the cultural environment of the engineering school or the quality of engineering instruction, may we not legitimately suspect that the phenomena are quite beyond the control of the school? Perhaps we may even suggest the hypothesis that the phenomena reported are beyond the control of the students themselves!

We tend to accept without question the inference that measured gains shown on successive applications of comparable subject-matter examinations are the result of teaching and learning efforts. The writers of the Pennsylvania report and their commentators have accepted this inference. They have also expressed the corollary inference that failure to show gains, individual and institutional, implies lack of effort or forthright poor teaching.

In the light of our own research results we are impelled to the view that the foregoing are not sound inferences. When we tried to interpret our results in terms of these inferences we found ourselves in a dilemma. The statistically derived facts did not fit these conventional explanations. Escape from the dilemma required a new hypothesis for explanation.

Our attention was first attracted to the situation when we considered the disparate results from attempts to distribute grades to 259 students in a first-year course in biology. The Biology Department had assigned its grades solely on the basis of total scores obtained on five long and well-constructed objective examinations. Comparable forms of the Cooperative Test Service biology tests had been given at the beginning and again at the end of the course. This test at the end of the course presumably reflected the *level* attained at that time in the subject-matter field—at least, that is the implication from the Pennsylvania study. Similarly, the difference in standard scores for each student on the two tests represented his gain achieved as the result of his instruction.

When we made a distribution of grades

[1] Learned and Wood, "The Student and His Knowledge," Bulletin Number Twenty-Nine, The Carnegie Foundation for the Advancement of Teaching, 1938, pp. 28 ff.

for these students, using level on the second standard test as a basis, and compared these grades with those awarded by the department, we found general agreement between the results. In a few instances students received C by one method as against F by the other, A by one and C by the other, or D by one and A by the other.

When we made a similar distribution using gains as the basis, we encountered startling disagreements. Students who deserved A's on this basis had received F's and D's from the department; others who would receive F's and D's by this method had received A's and B's from the department. These disagreements were so great and so numerous that we made a correlation study of the whole set of interrelationships among test scores, gains, grades and intelligence test results.

The results were unexpected and perplexing. In the sub-group numbering 217 who had taken a one-year course in biology in high school gains correlated only .04 with grades; while for the sub-group of 42 with no previous study of biology this figure was .19.

Still more disturbing were the relations between intelligence and gains. Here the figure for the larger group was −.14 as against −.29 for the smaller group. There must have been errors in the calculations: they were made again, independently, with the same results. Clearly, from these figures, the measured gains were significantly related neither to grades as awarded nor to intelligence as measured.

Why should we expect any other result? We have always awarded grades with the tacit assumption that they reflected achievement, attainment, growth, mastery or gain—partially if not wholly. It is apparent that this assumption is quite unjustified in the situation studied.

From the definitions of intelligence, implying as they do a mental alertness, a quickness to grasp, a readiness to learn, to meet new situations, to grow, as well as from the nature of the instruments used to measure this ability, it is a fair inference that higher intelligence implies an associated ability to make greater subject-matter gains. Not only is this not a correct inference, in the light of these results, but something slightly the opposite seems to be implied.

This must be a chance result, in spite of the odds against it, we thought. The American Council Psychological Examination is of known high reliability; The Cooperative Test Service standardized tests are known to be of high reliability; and the five objective examinations upon which grades were based were also found, upon subsequent analysis, to be highly reliable. Careful check of the figures disclosed no errors in the calculations. Perhaps the situation was peculiar to this course alone.

The following year the study was repeated, this time in a course in modern European history. The content was different, the methods of instruction were different and the basis for awarding grades was different. But the results were practically the same.

In two groups of 126 each, taught by different instructors, gains correlated .02 and .12, respectively, with grades; and −.19 and −.14, respectively with intelligence. The probability of such results by chance alone is infinitely small. We are confronted with a major dilemma.

In the meantime we had extended the biology study over two semesters with 88 students from the original group. For these students their first-semester gains correlated .23 with grades and .02 with intelligence; second-semester gains correlated .20 with grades and −.01 with intelligence. In the light of our previous beliefs this should not happen. But it has happened.

We must formulate an explanation that will fit these results. If the gains

are shown to be relatively independent of both scholarship in the usual sense, as well as independent of intelligence as usually measured, to what are they significantly related? We can not answer, because we have no data.

We may suspect that these measured gains reflect some underlying or innate growth factor, that they result from some obscure mental maturation process that continues long after the usual measured intelligence growth has attained its maximum. This seems to be a plausible hypothesis, but only a hypothesis.

We may suspect that the underlying function may take the form of known growth curves. We should then expect to find differences in the rates of acceleration of such curves for different individuals. We actually find a normal distribution of gains, indicative of such differences in acceleration.

We may further suspect—and this may be most important—that such curves will reach their maxima at different ages for different individuals, marking the points at which such growth stops. The failure of many students to show any gain, noted in the Pennsylvania Study as well as in our own, supports such an inference. Obviously, a student who has attained his maximum can not show any further gains any more than can the high-jumper who has attained his physiological limit show any further gains in the height of his jump.

To what traits of human behavior is this apparently dynamic function probably most closely related? We have long been puzzled by the continued personal growth of some students whose college records were poor and whose intelligence test scores were low. Could it be possible that their later attainments were due to this underlying function that had not attained its maximum?

We are similarly often disappointed by the failure of many brilliant students of high measured intelligence to achieve distinction after their college days. Could they have reached their maximum in this function during or soon after the completion of their college courses, resulting in an arrest of further growth? This may be a tenable hypothesis.

The function seems to be dynamic in character and as such some sort of "potentiality for growth," but it may be better to name it only with a symbol and restrict its meaning by a simple definition: *Iota Function—the function responsible for successive gains on comparable forms of standardized subject-matter examinations.* This will help to avoid the difficulties inherent in all descriptive labels.

The Iota Function seems to be firmly established as a mathematically verifiable phenomenon if not as a fact of sense-perception. What is the next step? Clearly we must measure its effects and record them over a sufficient period of time to permit us to learn more of its nature. We may never know any more about the function itself than we now know about gravitation, but we can learn much about its effects.

In the light of the foregoing hypothesis, how may we interpret the peculiar phenomena of the Pennsylvania Study? If measured gains are due to some innate growth factor, a factor apparently not significantly related either to scholarship or to intelligence as these are usually measured, the individuals and the institutions they attend are not to be praised or blamed for such gains. Neither can individual instructors be compared with each other in teaching efficiency on the basis of the gains shown by their students.

It is also apparently quite possible that the sizes of the classes taught may not affect this phenomenon. This possibility must be examined with care, since it may have an important bearing upon the economic aspects of education quite apart from the problem of administra-

tive control. The traditional arguments for the small, personalized classes and the small colleges themselves may be questioned.

How, then, are we to explain the differences in average gains reported among the colleges in Pennsylvania? The annual reports of the average standings on the American Council Psychological Examinations have shown certain colleges at the top, others at the middle, and still others at the bottom of the list, year after year. These relative positions are maintained regardless of the fact that many of the institutions do not use the test scores as a criterion for the selection of students. The same sort of selective factor that is responsible for this intelligence phenomenon is probably responsible for the gains phenomenon. In both instances this factor would seem to be operating largely without the volition of the admissions personnel.

If the differences reported are due to selection, failure to show gains can only be corrected by amendment of the selection procedures, not by changes in instruction processes. The problem becomes one of identifying prior to admission, the students having the greater promise of such subject-matter gains. This in turn implies suitable records of similar growth during the high school and possibly during the elementary school years.

If curves of subject-matter gains are deducible from previous records—records of comparable scores on comparable examinations—the task is comparatively simple. Sufficient data should make it easy to project the appropriate curves into and perhaps through the college years and afford a basis for the prediction of gains.

The lack of appropriate measurements during the pre-college years is the main obstacle to an immediate application of such selection methods. Nevertheless, if this Iota Function is as important as it seems to be, and its measured gains are to be made a criterion of academic success, the necessary data must be accumulated and made available to the colleges.

There are other implications of the Iota Function phenomena which extend beyond the college years. The hypothesis may be offered that students who show positive acceleration of their gains in their fields of major effort are the best candidates for the graduate and professional schools. Such students would seem to offer the promise of greatest personal accomplishments and most extensive contributions to their chosen professions. This hypothesis, too, requires experimental verification.

It is apparent that many of our traditional beliefs and some of our educational practices will have to be reexamined anew in the light of the Iota phenomenon. Perhaps we are wasting both time and money in misguided attempts at instruction. Perhaps we are dispensing both praise and blame where they are undeserved. Perhaps we are dealing with a fact of human nature which we can only control through human adaptation, as we now control the weather.

BOOKS ON SCIENCE FOR LAYMEN

MENTAL SICKNESS[1]

THE author of Ecclesiastes lived before the days of "popular psychology," else he might not have been so prone to understatement when he wrote, "of making many books there is no end"! The veritable flood of pulp magazines and books devoted to the alleged purpose of teaching the reader to "control his mind" and avoid mental disorder is an eloquent testimonial to a need for guidance and reassurance on the part of many individuals. This is not to say that good advice for the laity is not to be found in some books and in some reputable journals; even though self-prescription is usually dangerous, there are excellent volumes written primarily for non-medical readers and dealing with the nature of mental troubles and their prevention. The very avidity of the public, however, should cause the prospective author to be very sure of his facts and of his way of expressing them. Careless expression and oversimplification of statement may sometimes have untoward effects on the introspective reader.

The present volume is evidently meant for popular consumption. It is a bulky volume, consisting of 22 chapters, breezily written and loosely put together. Many brief case histories are given, interspersed with comments and rather sweeping statements, sometimes of highly doubtful scientific accuracy.

Alcoholism, one of the important examples of poor mental hygiene, is dismissed with a chapter of 2½ pages, while two chapters (31 pages) are devoted to schizophrenia and "how the schizophrenic speaks"—an important subject to the psychiatrist, but hardly so comprehensible to the lay reader as might be a discussion of the meaning of alcoholism. We are told that excessive smoking and excessive use of coffee are "a cause of restlessness" (p. 18) (probably they are more often the result!), and that "the importance of chronic constipation . . . as a cause or contributory cause of the most destructive diseases, mainly physical, but also mental, has not been emphasized strongly enough" (p. 366). Again, we learn that poverty is one of the causes of mental deficiency (p. 87), and that retarded children should never belong in the ungraded classes (p. 89)! A final scientific gem, following the statement that most homosexuality is acquired, runs thus: "Homosexualism is also spread in the so-called underworld, that is among prostitutes and their parasites, among people with low-grade mentalities and among the decaying European feudal nobility and money aristocracy in Europe and in America" (p. 123).

The motives of the author in attempting to present some understanding of mental processes are undoubtedly excellent. Unfortunately, the volume can hardly be termed sound or scientific, however readable it may be.

WINFRED OVERHOLSER, M.D.

[1] *Your Mental Health.* B. Liber, M.D. xvi + 408 pp. 1940. Melior Books.

UNITS OF LIFE[1]

THIS book presents a clear account of modern views concerning the nature of living things. Professor Gerard has succeeded in describing all the important vital functions in a readable, forceful manner which requires no specialized biological training on the part of the reader. The style is not dogmatic; many biological problems are introduced as essentially questions awaiting a final answer.

[1] *Unresting Cells.* R. W. Gerard. Illustrated. xiv + 439 pp. $3.00. 1940. Harper and Brothers.

The most attractive features of the volume are the original illustrations and diagrams—the skilful work of Elizabeth Buchsbaum. The figures take the form of cartoon sketches in which various forces at work in living systems are represented as active manikins and demons engaged in many amusing activities, such as carrying buckets of water, opening trap doors, selecting food in cafeterias and even marching up church aisles to the altar. In every case some important physiological fact is conveyed to the reader without distortion or exaggeration. It is amazing to find very complex physiological events so simply and clearly presented at a glance.

The plan of the book is logically arranged and gives first a description of the physical and chemical basis of living matter. Structural formulae are greatly clarified by clever diagrams. Then follow descriptions of types of living cells. The later chapters deal with growth, reproduction and heredity. The book closes with emphasis on the organism as a whole. The final focus of attention on the living being as an integrated unit is essential for a well-balanced presentation of physiology.

This reviewer believes that the book gives too much importance to the somewhat old-fashioned concept of "the cell." Thus connective and cardiac tissue have no "cellular" organization. Moreover, little is gained by including a spherical egg cell and a yard-long nerve fiber under the same category. Professor Gerard, of course, points out these difficulties.

The book would be improved by a chapter or section dealing with physical models representing physiological function. A drop of mercury will pulsate like a heart if touched with a needle. All the electrical properties of living systems can be duplicated by physical models consisting of layers of oil in simple solutions that Dr. Beutner has described. The addition of a bibliography, too, especially of works of a general nature, would be of great value to the many readers who will be inspired to follow the subject of physiology in greater detail.

The book is by far the clearest and most comprehensive presentation of modern general physiology for the layman, and closes with the encouraging statement that "The huge weight of biological experience must give us strong hope that civilization is not doomed to destruction."

T. Cunliffe Barnes

IS INFLATION AROUND THE CORNER?[1]

Every great war in modern times has been accompanied by a large increase in commodity prices, followed by an equally marked decline. Inflation has also followed excessive national debt, as in France about 1790 and in Germany after the World War I. The United States is virtually involved in war, and it is adding billions and billions of dollars to an already unparalleled debt. Consequently, millions of people are anxiously inquiring whether inflation now menaces the purchasing power of their accumulations in life insurance policies and other dollar securities, including the social security annuities provided for by the government.

Dr. Hardy does not categorically answer these inquiries on the basis of the many precedents history offers nor by arguments based on classical economic theories. Instead, he starts with the fact that the United States is committed to a prodigious war mobilization of men, materials and machines, and he inquires how this great effort can be made with the minimum of disturbance to the economy of the country and consequently

[1] *Wartime Control of Prices.* Charles O. Hardy. x + 212 pp. $3.00. 1940. The Brookings Institution.

with the maximum of efficiency and overall good. Perhaps this approach was stimulated by the fact that the investigation was made at the request of the War Department. In any case, it is excellent.

The book opens with an introductory chapter consisting of a clear and very readable statement of the systematic manner in which the question is analyzed and answered. No description can give as clear an idea of the approach as a mere list of the points raised and discussed. Part I consists of an analysis of the factors involved in the determination of the prices of commodities in times of war; and Part II consists of a review and appraisal of the price advances and the controls of them that were used or attempted during World War I, with constant references to the considerations presented in Part I.

The questions considered in the Introduction are indicative of the analyses in Parts I and II. Among these subjects are: "What are the sinews of war? What part does money play in the mobilization of a nation's resources for war? What is the significance of price in a war economy? Large government purchases on a competitive basis. Speculation in commodities. Uncoordinated government buying. Competitive bidding for labor. The expansion of bank credit. Does price inflation tend to expedite or to retard effective mobilization for war? How does price inflation affect the distribution of the war burden among the various groups in society? Does price inflation serve to increase or decrease the cost of a war to the nation? What is the economic aftermath of wartime price inflation? Does government borrowing through bank credit expansion shift the burden of a war to future generations? Is it possible to finance a war entirely from taxes and from loans paid out of current income?"

There should be no surprise that these questions relate so explicitly to the war, for it is the primary occasion for the whole question of possible inflation and its effects. Any controls or attempted controls that may be devised must be subservient to the primary purpose of rearmament.

The conclusion reached by the author is "that a serious inflation of prices in time of war can be prevented. The explanations of the great price inflations in past wars is to be found in an unsound fiscal policy; in part in the unrestrained use of the competitive price mechanism as a means of bringing about war mobilization, and in part in the adoption of faulty principles of price control when finally the necessity for control was discovered."

In view of the disastrous consequences that would result from inflation, we may fervently hope that those who perhaps can prevent it will have the wisdom, the legal power and the administrative ability to act effectively when action is necessary. And if all these conditions are met we shall have lost, at least for a time and perhaps permanently, some of the liberties we have traditionally cherished.

F. R. MOULTON

WAR CORRESPONDENCE FROM THE CANCER FRONT[1]

EXCITING as a report of battle and yet as charmingly human as an intimate conversation is the little book just off the press in which Dr. Sokoloff tells the story of the fight against cancer. With rare skill the author has beautifully succeeded in reporting briefly some of the outstanding achievements in cancer research and in defining the complexities of the problem. While never denying the tragedy of neglected cancer, the book is filled with the sunshine of hope; hope that the advance of knowledge through tireless research and that the dissipation

[1] *Unconquered Enemy.* Boris Sokoloff. x + 198 pp. $1.75. 1940. The Greystone Press.

of knowledge through persistent education will prolong many lives and prevent much suffering now unnecessary. Avoiding sentimentality and emotional appeal through sensationalism, the author has been able, nevertheless, to infuse a living enthusiasm and interest by his excellent thumbnail sketches of scientists at work.

The style is exceptionally appropriate to presentation of scientific data and concepts to laymen. One reads quickly, with pleasure and interest. With a fine comprehension of values Sokoloff paints the grandeur of research. The scientific facts are sound, and his critical appraisals of present investigations impartial. Naturally, much factual and theorectical knowledge of neoplasmata is omitted for the sake of brevity and simplicity. The book is enthusiastically recommended to those whose interest in cancer is neither technical nor very profound.

EDWARD J. STIEGLITZ

CONTROL OF DEVELOPMENT, DIFFERENTIATION AND GROWTH[1]

IF, at an early embryonic stage in development, especially of the amphibian egg, parts of the outer cell membranes from which the neural groove would develop are transplanted to another part of the embryo, there will be formed in the new place a neural tube, and also appropriate adjacent structures, such as would otherwise never have developed in that place. To account for this phenomenon the hypothetical substance called by Spemann "the organiser" has been invoked. The author of the present book, who is a nomenclatorophile, likes to call this, or the substance it produces, the "evocator." The gene is in some way responsible for the development of organs in their normal place in the normal embryo. The author, an experienced embryologist, says of his book: "I have devoted some space to point out the similarities between the concepts derived from the consideration of the organiser and those which arise in connection with the developmental effects of genes."

Of his book the early chapters are devoted to this evocator and the search for its chemical nature. The search for the substance that organizes development, or calls forth a new part, has so far not been crowned with much success. The author, working with Joseph Needham, also of Cambridge, England, has finally reached the conclusion that the substance belongs to the group of sterols. But the history of their search reminds one of Loeb's search for the substance that the sperm brings into the egg to start its development. After announcing the discovery of several, one after the other, Loeb concluded that a variety of agents might start development of the parthenogenetic egg when the egg was all ready for fertilization. In similar fashion some experiments report that mechanical irritants, such as silica or certain substances that injure the cell, may "evocate." Now the conclusion seems to be that the evocator evocates the evocatable. This is not a great advance over Aristotle's epitome of the ontogenetic process: Part acts on part. Still, concentration on the study of the organizer and the conditions under which it is active is opening up a new field of research which the author describes in this volume in some detail.

In his discussion of genic action the author gets farther. His chapter on the temporal course of gene reactions is good, but he does not perhaps sufficiently emphasize the fact that the time of first appearance of a new organ is not necessarily the time at which the anlage of

[1] *Organisers and Genes.* C. H. Waddington. 160 pp. $3.00. 1940. Cambridge University Press.

that organ has been formed. Even the anlage has precursors that might in some cases be traced back to the fertilized egg.

A chapter is devoted to "individuation," which is the author's preferred name to differentiation. As he points out, the process of individuation is different from the process of evocation. The evocator changes from time to time, or the substrate upon which it acts does, so that in the course of development new and different structures are added to the earlier and less differentiated ones.

The author's synthesis of the action of organizers and genes is not quite as complete as might have been hoped for. Both are responsible for development at different stages, but there is no good evidence that they work in the same way.

The book is a useful and successful attempt to bring together the observed facts of the action of the hypothetical organizer and many of the effects of the action of the gene. One is grateful to the author for directing attention to the physiological factors which control development, differentiation and growth. The bibliography is full and up to date. The book will be a useful addition to the library of the biologist.

CHAS. B. DAVENPORT

NEW MANKILLERS[1]

THIS is a very interesting book. It contains much material informative to those not already familiar with the field covered. There are relatively few errors of statement.

Unfortunately, the authors were limited by choice, or otherwise, to about 150 pages in which to present a topic almost encyclopedic in scope. They present various phases of their subject under the chapter headings: the soldier, man-made killers, the machines of modern warfare, crucibles of death, the chemical industry. These chapters are followed by an appendix and a bibliography. The topics discussed progressively increase in scope and in unsatisfactory treatment.

Chemical warfare is discussed under the somewhat lurid title of "Crucibles of Death," and attempts to cover in 40 pages the history of the development of chemical warfare itself, the great variety of materials used, and the tactics of their use.

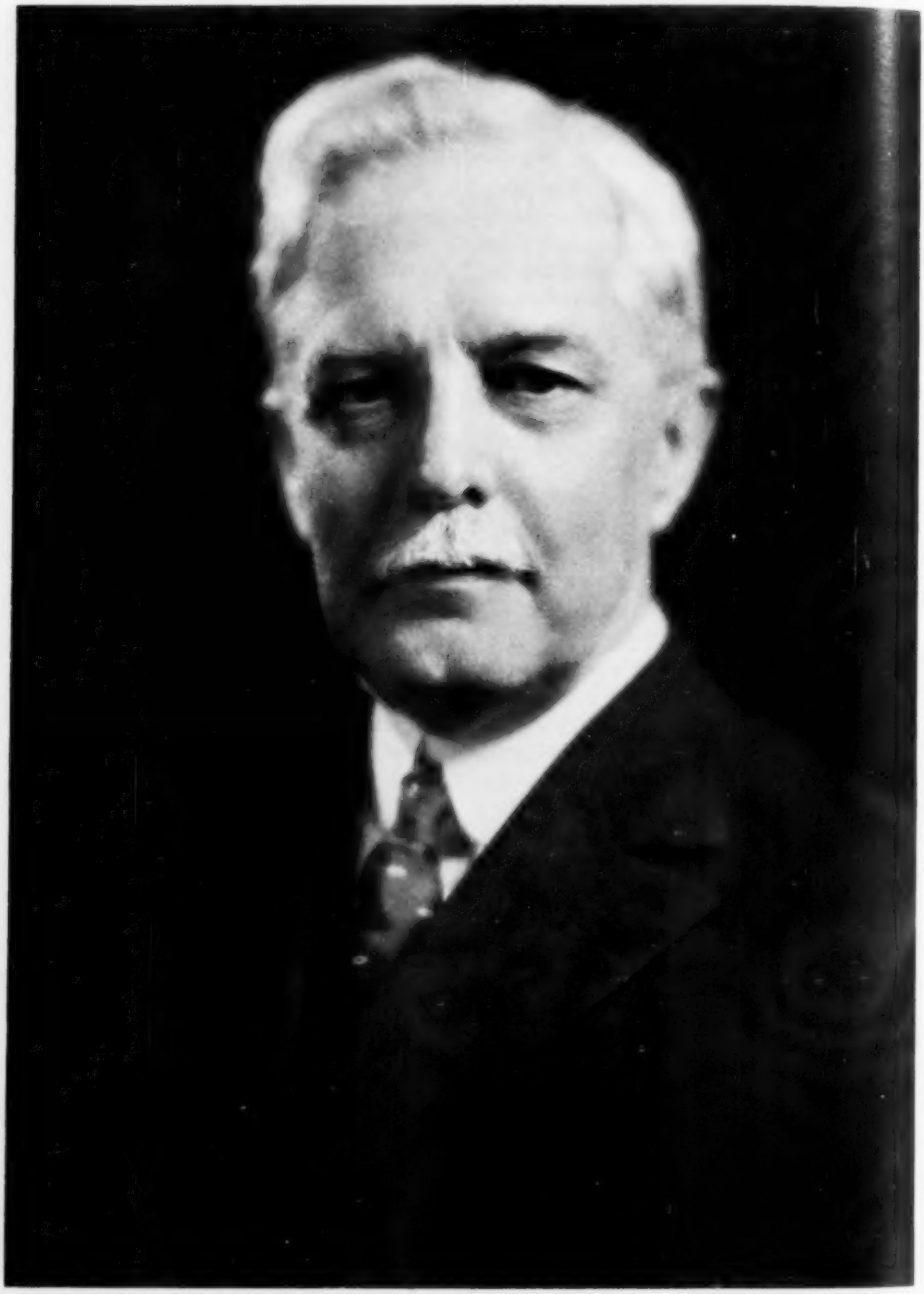
The 16 pages devoted to the chemical industry contain a collection of fragmentary data. The 23 pages of the Appendix give technical information concerning a wide range of topics. The attached bibliography may constitute the more important sources from which the data in the book have been collected, but almost no specific references are given in the text. Throughout the book there is an obvious attempt to laud the work of American chemists and to present this laudation in a colorful manner.

With so many attempted objectives it is not surprising that the authors have attained none of them in a very satisfactory manner.

Despite the severity of the criticism implied and expressed above, the book is not without considerable merit. It provides the technical man with a few hours of very interesting reading and permits an appreciative evaluation of the topics outside his particular field. The non-technical reader may not gain much actual information, despite the popular style of the book, but will probably get a better appreciation of the tremendous impact of modern war on the civilian population and of the importance of technical preparation and of capacity for production of war materials.

HORACE G. BYERS

[1] *Chemistry in Warfare: Its Strategic Importance.* F. A. Hessel, M. S. Hessel and W. Martin. Illustrated. 164 pp. 1940. Hastings House.



DAYTON CLARENCE MILLER

THE PROGRESS OF SCIENCE

DAYTON CLARENCE MILLER, RENOWNED PHYSICIST

THE Case School of Applied Science suffered a great loss in the death of her noted physicist, Dr. Dayton Clarence Miller, on February 22, at the age of 74 years.

Dr. Miller had taught at Case for more than fifty years and had been head of the department of physics from 1893 until his retirement in 1936. In 1927 he had been made Ambrose Swasey research professor of physics. Upon his retirement the Case trustees bestowed upon him the title "Honorary Professor of Physics" for life, and at their request he continued as acting head of the department until the fall of 1939.

Internationally known for his work in quantitative measurements of light and sound and as the inventor of the Phonodeik, which turns sound waves into a moving beam of light upon a screen, Dr. Miller was at the same time a modest and lovable teacher, always searching for the truth and ever interested in the problems of his students.

Dr. Miller's work in the field of acoustics was widely recognized. He studied acoustics in relation to auditorium design and drew the sound specifications for some of the large auditoriums throughout the United States. Among these auditoriums are Severance Music Hall, the Epworth-Euclid Methodist Church and the First Church of Christ, Scientist, in Cleveland, and the chapels at Denison University, Bryn Mawr College, Princeton University, the University of Chicago, and he was consulted concerning the acoustics of the National Academy of Sciences building in Washington, D. C. In addition to these major structures, Dr. Miller designed specifications for about a hundred other churches, theaters, hospitals, offices and large and small auditoriums.

Another achievement was in his research on "ether drift," in which he sought proof of the earth's motion through the ether of space. This research followed the famous Michelson-Morley ether drift experiments of 1887, which originated on the Case campus. This research, both in Cleveland and at Mt. Wilson in California, was carried on by means of the interferometer, a mechanism which splits a ray of light into two parts traveling at right angles to each other. These beams are reflected back and forth by mirrors over a distance of 200 feet. Dr. Miller's ether drift studies, beginning in 1901, were led to the conclusion of a positive drift, on which he presented a paper before the National Academy of Sciences meeting at Princeton University on November 18, 1929. Full publication of these studies was made in 1933.

Dr. Miller was a member of many learned societies, including the National Academy of Sciences, and in several he held important offices. For three years he was chairman of the Division of Physical Sciences of the National Research Council of Washington. Since 1914 he was a member of the council of the American Physical Society, and served as secretary from 1918–1922, vice-president in 1923–24 and president in 1925–26. He served as secretary of the physics section of the American Association for the Advancement of Science in 1902–06, was vice-president in 1907, was secretary of the council in 1908 and general secretary in 1909. Besides membership in these societies, Dr. Miller was a member of thirty-three other organizations whose interests lay in the fields of physics, astronomy, acoustics, optics, engineering education, mathematics, scholarship and music.

Dr. Miller's degrees are many. He graduated from Baldwin-Wallace College with the degrees of bachelor of arts in 1886 and master of arts in 1889. In 1890 the degree of doctor of science was

conferred upon him by Princeton University. Since then he has received five honorary degrees: doctor of science from Miami University in 1924; from Dartmouth, in 1927; doctor of laws from Western Reserve University, in 1927; and the same from Baldwin-Wallace, in 1933. Case School of Applied Science conferred the degree of doctor of engineering in 1936.

In addition to his many degrees, Dr. Miller possessed several medals for distinction in his scientific work. In 1917 and again in 1927 two medals were presented by the Franklin Institute. In 1925 he won the $1,000 prize of the American Association for the Advancement of Science, and the City of Cleveland gave him the medal for distinguished service in 1928.

W. E. WICKENDEN
PRESIDENT, CASE SCHOOL

ASTRONOMY SECTION OF SMITHSONIAN'S NEW INDEX EXHIBIT

THE purpose of the new index exhibit in the main hall of the Smithsonian Institution in Washington is to provide for visitors a concise portrayal of all the activities of the institution. The subject of each section of the exhibit is announced in large letters at the top of the panel, with a brief definition of the science or other activity below this title. Each section is developed around a central theme, which symbolizes the subject represented by means of a working model, diorama, painting or other medium. Flanking this on either side are models, specimens, paintings and other objects to visualize the Smithsonian's contributions to the particular field of investigation. All the exhibits are recessed behind glass and illuminated from above or behind.

The first subject portrayed, astronomy, is defined as "the study of celestial objects." The central theme is a diorama measuring about 2×3 feet representing the central room of a hypothetical space ship. The observer, apparently looking out from the nose of the ship, sees before him, against a black background spangled with stars, the globe of the earth with its familiar con-

ASTRONOMY SECTION OF SMITHSONIAN'S NEW INDEX EXHIBIT

CROSS-SECTION OF A SMITHSONIAN OBSERVING TUNNEL

TO KEEP TEMPERATURE CONDITIONS CONSTANT THE DELICATE MEASURING INSTRUMENTS ARE MOUNTED INSIDE A TUNNEL NEAR THE TOP OF THE MOUNTAIN. THE SUN'S RAYS ARE REFLECTED BY MIRRORS. THE INTENSITY OF THE RADIATION IS RECORDED ON PHOTOGRAPHIC PLATES. CAREFUL STUDY OF THESE ENABLES THE OBSERVER TO CORRECT FOR LOSSES IN THE EARTH'S ATMOSPHERE.

SUN'S RAYS LIGHT THE EARTH

THE EARTH LIGHTED ON ONE SIDE BY THE RAYS OF THE SUN AS IT WOULD APPEAR FROM A HYPOTHETICAL SPACE SHIP.

tinents and oceans. The earth, revolving slowly, is brilliantly illuminated on one side and dark on the other. The label emphasizes the importance of the sun's rays to life on the earth.

On the left-hand panel are transparencies in color of two of the Smithsonian solar observing stations—one on pine-covered Table Mountain, California; the other on barren Mount Montezuma, Chile, near the great nitrate desert. Adjoining these a very complete model in diorama form visualizes a mountain-top observing tunnel at one of these stations. The cut-away side of the mountain reveals a cross-section of the tunnel with all the instruments reproduced in miniature. Even the beam of sunlight reflected in by the clock-driven coelostat appears in the form of a tiny strip of Cellophane. The intensity of the solar radiation, as measured by an electrical thermometer sensitive to one millionth of a degree, records itself automatically on photographic plates in these tunnels, and one of the actual plates is mounted below the model.

The right-hand panel displays two of the instruments constructed under my direction in the course of the Smithsonian's solar investigation, namely, the silver-disk pyrheliometer for measuring in calories the total solar radiation, and the solar cooker, one of a series of instruments devised to produce heat and power directly from the sun's rays.

ABBOT SOLAR COOKER

ON A CLOUDLESS DAY THIS MODEL CAN UTILIZE THE SUN'S RAYS TO BAKE A CAKE IN HALF AN HOUR OR RUN A SMALL STEAM ENGINE. LARGER DEVICES FOR DISTILLING WATER, COOKING, REFRIGERATING OR OPERATING STEAM ENGINES HAVE BEEN CONSTRUCTED AND DEMONSTRATED.

The astronomy exhibit is completed by two placards calling attention to the purposes and results of the Smithsonian's study of the sun.

C. G. ABBOT,
SMITHSONIAN INSTITUTION *Secretary*

THE SNOW MOUNTAINS—NEW GUINEA GROUP IN THE AMERICAN MUSEUM OF NATURAL HISTORY

THIS recently installed exhibit portrays alpine conditions in the center of New Guinea, an island about 1,500 miles long by 400 in greatest width, and lying just below the equator. Chains of mountains extend, like a backbone, along the length of the island, reaching their greatest height in the Snow Mountains of Netherland New Guinea, where six peaks are eternally snow covered. The highest, Mt. Carstensz, reaches an altitude of 16,600 feet. The southeast trade winds bring a dry season to parts of the south and southeast coasts, where savanna country prevails, but the rest of the lowlands are humid, with dense tropical vegetation. Going up from these lowlands, one passes through belts of oak and beech forests to pines, tree-blueberries and rhododendron, and finally to alpine grassland and snow.

The view in the group is looking southward across Lake Habbema, which reaches 11,000 feet above the sea, toward Mt. Wilhelmina, the third highest peak. In the left foreground is a dark forest

A VIEW OF MT. WILHELMINA IN THE SNOW MOUNTAINS
TO AN ORNITHOLOGIST NEW GUINEA RECALLS BIRDS OF PARADISE. HERE TWO SPECIES ARE SHOWN: A GROUP OF MACGREGOR BIRDS OF PARADISE PERFORMING THEIR COMMUNAL DANCE ON A PINE BOUGH, AND JUST BELOW THEM A LONG-TAILED, SPLENDID BIRD OF PARADISE.

of pine and tree-blueberry, festooned with liverworts and mosses and enlivened with orchids; at timberline this gives way to grassland with many brilliant flowers. On Mt. Wilhelmina itself, the last few thousand feet are bare rock, capped with snow. Around the lake marshy areas add to the diversity of the country.

New Guinea has an extraordinary richness of bird life, with perhaps 500 breeding species. Bird life especially

QUAIL FROM THE SNOW MOUNTAINS
DETAIL OF THE ALPINE GRASSLAND SHOWING TWO QUAIL WALKING AMID BUTTERCUPS AND DAISY-LIKE FLOWERS NEAR THE EDGE OF A DRIED-UP POOL.

characteristic of New Guinea includes the birds of paradise, honeyeaters, pigeons, parrots and lories, kingfishers, cuckoo shrikes and flycatchers. Examples of five of these groups are shown in the exhibit. Most of the birds shown have never been exhibited before. Four of them were unnamed before last year.

The group was collected in the course of Mr. Richard Archbold's third and most spectacular expedition to New Guinea, known as the Indisch-Amerikaansche Expeditie. The expedition, in cooperation with the Netherlands Indies Government, concentrated on an altitudinal survey of mammals, birds, plants and insects from sea level to snow line on the north slope of the Snow Mountains. The success of the whole expedition, as well as the collecting of the group, was made possible by the use of the large flying boat *Guba*, which flew the party of more than 100 men, including carriers and a military escort, to Lake Habbema, and supplied them with food for their stay of nine months. Here the *Guba* operated from a higher altitude than had any flying boat previously. To have even reached the points inland by boat and on foot, the only other modes of travel possible, would have been an achievement. By the use of an airplane the party had ample time for studies, and was able to send out in addition to specimens such bulky material as the accessories for the group.

A. L. RAND

JUNGFRAUJOCH, THE HIGH-ALPINE UNIVERSITY

ON the Jungfraujoch, in Switzerland, at an altitude of 11,340 feet, there stands a castle-like, massive stone building of two floors, with a solid-looking tower. This is the High-Alpine Research Institute. A visit to this building reveals scientific equipment many a university would be proud of—practically installed working rooms and splendid laboratories with the most up-to-date instruments. High up in the tower is the library, a comfortable, oak-panelled room where innumerable volumes of scientific works are at the disposal of the scientists. A permanent supervisor is in charge; he is probably the "highest" beadle. For visiting scientists there are comfortable dormitories and two-berth cabins, as well as a kitchen for the preparation of their meals—things one does not usually associate with scientific research stations. Adjoining the building are stables where a certain number of animals are kept for experimental purposes.

Courtesy Willy Haller, Zurich

TRAIN OF THE JUNGFRAU RAILWAY IN SWITZERLAND BETWEEN KLEINE SCHEIDEGG AND EIGER GLACIER.

Although this building was only started in 1929 and completed in 1931, the history of the Jungfraujoch High-Alpine Research Station dates back to 1894. It was then that Adolf Guyer-Zeller, the creator of the Jungfrau Railway, undertook to support science in its endeavors to extend research to high altitudes. A clause of the railway com-

Courtesy A. Klopfenstein

THE ALETSCH GLACIER, FIFTEEN AND ONE-HALF MILES LONG

FROM JUNGFRAUJOCH, SWITZERLAND, CONVENIENTLY REACHED BY MOUNTAIN RAILWAYS, ONE ENJOYS A GLORIOUS OUTLOOK ON THIS GLACIER, EUROPE'S MOST GIGANTIC "RIVER OF ICE."

pany's concession obliged them to set aside considerable funds for the erection and the maintenance of a permanent observatory for meteorological and terrestrial-physical observations.

The Jungfraujoch Research Station was originally housed in a wooden pavilion erected on the plateau in 1925 by the Central Federal Meteorological Institute with the collaboration of the Jungfrau Railway Company. This was only a provisional arrangement until the meteorologists were able to take over their permanent home.

The Swiss Society for Natural History Research, which had been commissioned by the Federal Government to carry out the latter work, experienced great difficulty in finding a suitable site. The spot had to be freely accessible in all weather conditions. The solution was found by the Jungfrau Railway Company, when, in the spring of 1927, the "Sphinx" gallery was driven through to the Jungfraufirn. The new building was placed at the exit of this gallery. Thus the stately house on the south slope of the Sphinx came into being.

The institute undertakes research and investigations of a medical character, in physics (particularly cosmic rays), botany, zoology, etc. But astronomers also wanted to make use of this new home of science on the Jungfraujoch. The observatory of Geneva University accepted the task of installing a "branch" on the Jungfraujoch. Now a solid stone building is perched like an eyrie about 130 feet above the exit of the Sphinx gallery on the east slope of the Sphinx. But meteorology, which had been given priority in the Jungfrau Railway concession, was still without a home.

Unfortunately the Research Station itself did not possess the necessary funds wherewith to erect the required building. So "Sphinx Limited, Jungfraujoch" was formed in August, 1936, for the purpose of erecting the necessary buildings. Thorough investigation by famous meteorologists had led to the conclusion that the peak of the Sphinx would be the

Courtesy L. Beringer

SCIENTIFIC INSTITUTE AND NEW METEOROLOGICAL OBSERVATORY

JUNGFRAUJOCH, BERNESE OBERLAND, SWITZERLAND, 11,340 FEET, HAS THE LOFTIEST ALL-YEAR SETTLEMENT IN EUROPE. IT CONSISTS OF THE BERGHAUS HOTEL, THE JUNGFRAUJOCH RAILROAD STATION, THE HIGH ALPINE SCIENTIFIC INSTITUTE JUNGFRAUJOCH, AND TO TOP IT ALL, ON THE SUMMIT OF THE SPHINX ABOVE, 11,729 FEET, THE NEW METEOROLOGICAL OBSERVATORY JUNGFRAUJOCH.

most favorable spot for the new observatory. But again the problem of safety and accessibility had to be solved. A suspension railway from the Research Institute to the peak would have been too much exposed to weather and would have been useless at certain periods of the year. Thus it was decided to make use of the existing Sphinx gallery and to drive a shaft for a lift from here to the peak. In the summer of 1937 the erection of a solid stone building on the peak of the Sphinx, 11,716 feet above sea level, was completed. The observatory is at the free disposal of the Foundation "High-Alpine Research Station of the Jungfraujoch" and the Central Federal Meteorological Institute. Meteorological observations and weather forecasts from the peak of the Sphinx mountain are not only very important for mountaineers and skiers, but also render invaluable services to international aviation. The Swiss Alpine Club expressed its great interest in the erection of the meteorological station on the towering rock of the Jungfraujoch by subsidizing the scheme with a substantial amount of money.

Nowadays the Jungfrau Railway conveys not only numerous tourists to the lofty heights and beautiful Alpine scenery of this glacier district, but also an ever-increasing number of explorers and scientists eager to extend their investigations to hitherto unknown regions. During the five years since its completion, 184 scientists from every part of the world have taken advantage of this unique opportunity to carry out research work at this high altitude under the most auspicious conditions. They all study the same theme, namely, the influence of high altitudes on men, animals and plants, and apply the results for the benefit of humanity.

THE SPECTROSCOPE—THE MASTER INSTRUMENT

In the days of Newton the producers of refracting telescopes were in despair because when a beam of light passes obliquely through a refracting surface its direction is not only changed but it is spread out into its component colors. The result was that the refracting telescopes of the time formed separated images in various colors, each at a different distance from the objective, and consequently no definite focus was obtained. For this reason Newton and later Herschel turned to the use of reflectors which do not have this unfortunate property. It is altogether probable that observers of the time often thought that if they had directed Creation they would have had precisely the same refraction for all colors, and therefore much better telescopes for exploring the wonders of the heavens.

Alas for the silly opinion that man could improve on Creation! Dolland soon learned how to overcome largely the difficulties due to dispersion of light in refraction. And a thousand times more important, the dispersion of light of which the contemporaries of Newton complained was precisely the one of its properties that made possible the spectroscope, concerning which, upon receipt of the Rumford Medals of the American Academy of Arts and Science, Professor George R. Harrison, director of the Research Laboratories of Experimental Physics and of Applied Physics at the Massachusetts Institute of Technology, spoke in part as follows:

The spectroscope has become what appears to be the most powerful single tool which has yet been developed by the hand and mind of man, and one which is suited to a wide variety of purposes. Henry Norris Russell has called the spectroscope the "Master Key of Science," and an examination of the uses of the instrument reveals an astonishingly wide variety of applications. Recently I had occasion to list the various uses of the spectroscope; I found that it has been applied to such remarkably divergent purposes as the measurement of the ratio of the charge of an electron to its mass; determination of the weight of a star; detection of atoms present in a mixture of other atoms in amounts smaller than one in ten million; the measurement of the amounts of lead, arsenic and other poisons in foodstuffs; observation of the numbers of atoms entering and leaving molecules in a solution or vapor; calibration of the vitamin potencies of food samples; determination of the atomic constitution of complex molecules such as those of hormones and vitamins; measurement of the temperatures, sizes, distances and ages of stars; observation of the number and arrangement of electrons in atoms, and of atoms in molecules; the identification of criminals from traces left at the scene of a crime or carried from it; the study of the colors and discoloration of pigments and papers and ceramic glazes; the investigation of the origins and constitutions of minerals; and so on and on.

To the astronomer the spectroscope is at once a yardstick, a thermometer, a chronometer, a stethoscope for star-pulses, an analyzing microscope, a chemical balance and a super-telescope of the heavens. I think President Shapley will agree with me that though without the telescope the spectroscope would have little value to the astronomer, the spectroscope in its turn has multiplied the power of the telescope by perhaps twenty—for though it is the function of a telescope to gather light and focus this is an image or a spot, a spectroscope can separate this light into its component parts and thus lay bare a dozen meanings hidden from the eye.

To the physicist the spectroscope has served as a powerful atomic probe, for with its aid in analyzing the light emitted by atoms he has deduced much about their structures. He has found that light is emitted when atoms or molecules lose energy as the result of transitions of an electron from a position involving greater energy to one involving less; the spectroscope reveals the exact size of the photon which an atom emits under such circumstances, and by means of the quantum theory the physicist can picture what is going on in a tiny atomic system which is not more than ten or twenty billionths of an inch in diameter.

To the chemist, the biologist or the metallurgist, the spectroscope serves as a sensitive analytical instrument, to detect small amounts of impurities, or to analyze the atomic constitution of a speck of matter from its emission of light, or its molecular constitution from its absorption of light. Nor is the use of the instrument as a thermometer confined to the astronomer, for the engineer who wishes to determine the temperature of engine flames need only put a transparent window into the cylinder of a motor and use the spectroscope to study the light which is emitted.

F.R.M.

A NEW METHOD FOR STAINING CHROMOSOMES AND NUCLEOLI

Many of the advances in biology have depended on the development of a new technique or method. This is particularly true in cytology, where everything depends on getting a clear picture which will show the exact relationship of the parts studied. Further advances in the study of nuclear structure are made possible by the development of a new staining method which sharply differentiates the nucleoli from the chromosomes in a cell nucleus.

With the gentian violet-iodine staining method, which has been widely used by cytologists during the last fifteen years, the chromosomes and nucleoli stain alike, whereas with the new Feulgen-Light green stain the chromosomes are red and the nucleoli green. This result was attained by first staining with Feulgen, which is a specific stain for chromatin. The chromosomes are stained a bright red and all other parts of the cell are unstained. This is followed by the use of a mordant—5 per cent. sodium carbonate—which gives the nucleoli an alkaline reaction. The material—sections or smears of tissue—is left in the mordanting solution for an hour or more. The most satisfactory length of time varies from one genus of plants to another.

After thoroughly washing out the sodium carbonate, the material is stained for about ten minutes in an alcoholic solution of light green. This stains only the nucleoli and the matrix, or sheath around the red chromatin core of the chromosomes.

In recent years it has been shown that the nucleoli arise from chromosomes which have a satellite. This is a small globule of chromatin attached by an extremely delicate thread to the end of the chromosome proper. The nucleolus takes its origin, at least in many cases, from the tip of the chromosome at the point where the satellite thread emerges. With the new stain the origin and growth of the nucleolus can be followed from its earliest stages. In early telophase of mitosis all the nucleoli are separate, each being produced by a different chromosome. Such chromosomes have either a satellite or a secondary constriction producing a nucleolus farther from the end of the chromosome.

It is now known that in a number of genera, such as Oenothera and Oryza, which are generally regarded as ordinary diploid plants with only two sets of chromosomes, there are four chromosomes which each produce a nucleolus. Later, in the resting stage of the nucleus, they are generally fused into one. The presence of four is an indication that these plants are secondary tetraploids in which some of the chromosomes are represented four times. In rice particularly we have shown that the twelve pairs of chromosomes must have been derived from an ancestral condition with five pairs, which is the basic chromosome number for the whole grass family. It has similarly been shown that four is the basic number for the Leguminosae.

The Feulgen-Light green stain has now been applied to a long series of plant genera. It is found that the study of satellites and nucleoli by this method throws a great deal of light on the origin and relationships of plant species and genera and is of great value in the tracing of nuclear phylogeny. It is believed that the stain will be equally useful in animal cytology.

R. Ruggles Gates
Professor of Botany,
University of London

SALT OF THE EARTH

A recent report by O. F. Poindexter and R. A. Smith on the enormous salt deposits in Michigan contains, by implication, a marvelous story written by the geologic processes some 400 or 500 million years ago.

In the Salina Basin alone there is an area of about 30,000 square miles in which deposits of salt have an aggregate thickness ranging from 500 to 1,200 feet. Conservative estimates place its total volume at 3,000 cubic miles, and its weight at 480,000 million tons. There is, therefore, no occasion for worry lest salt, an indispensable natural resource, will be exhausted, for this deposit alone is sufficient for the physiological needs of the whole human race, at its present numbers, for 200 million years. In addition, there are other comparable deposits of salt in various parts of the earth, not to mention enormously greater amounts in the oceans. In some regions, however, salt has been so scarce as to have been in earlier days an almost precious commodity.

Concentrations of salt, like those of other minerals, have been produced by the leisurely action of geological agencies. On the whole the history of salt deposits has been comparatively simple. From very ancient geological times, at least 2,000 million years ago and possibly from a billion years farther back, the waters that fell as rain or snow gradually disintegrated rocks and carried salt and other compounds dissolved out of them into the sea. By 500 million years ago the oceans had acquired a considerable degree of salinity. At that time life had been in existence on the earth for at least 1,500 million years, during which it had evolved from the low level of the blue-green algae up to that of corals and trilobites.

Even as early as 500 million years ago the lowly organisms that had lived up to that time had been important geological agencies and had produced astonishing results. For example, certain forms had precipitated the lime that is still spread in layers hundreds of feet thick over areas of hundreds of thousands of square miles. And, too, it was certain forms of life, bacteria, which were instrumental in the final concentrations of iron in such ores as those of the Lake Superior District. But salt had a more lowly origin; it was precipitated from the vanishing waters of drying seas. At the beginning of the Ordovician period, about 450 million years ago, nearly two thirds of what is now North America lay beneath the waters of a shallow sea. For 200 million years the waters several times alternately withdrew and spread widely over the continental area. In some of these great oscillations there were arid periods during which the water was evaporated from land-locked areas, leaving behind the salts that were dissolved in it.

Many substances are in solution in sea water, the most abundant of which is ordinary salt. There is, in addition, about one seventh as much magnesium chloride, one sixteenth as much magnesium sulfate and lesser amounts of compounds of calcium and potassium. If these various substances were left mixed together by vanishing seas, the difficulty of separating them now would be great. But they are precipitated at such different concentrations that often in the slow process of evaporation they are almost completely separated. It is because of this fact that there is now in Michigan enough almost pure salt to meet the requirements of the human race for many tens of millions of years.

The fact that the salt in Michigan was deposited during long arid periods raises the question whether the rains may not fail again over most of North America. No scientist would assert that they will not cease to fall in some remote future, perhaps for long intervals. But there is no thought that the droughts of the past few years is the beginning of such an era, for it is almost certainly a temporary deficiency produced by many minor cycles. For the near future, there is little danger; in long intervals great

changes are probable, changes that may make large areas of the earth uninhabitable by higher forms of life.

Indeed, we may look beyond the earth for possible causes of disaster, because our sun and its retinue of planets, according to recent conclusions reached at the Mount Wilson Observatory, make a circuit of our galaxy in about 200 million years. In such wide excursions among vast nebulae and billions of stars there are possibilities of an immersion of our system in wide-spreading nebulous materials and even of a disastrous collision with another star.

It is not intended, however, to emphasize the existence of that "bourne whence no traveler returns," for as a matter of fact science marks out a pathway that will be pleasant for those who take it. It is dissipating with light the superstitious fears that throughout history have darkened the lives of mankind.

F. R. MOULTON

EUGENICS AND WAR

WHILE there is yet time it behooves us, as eugenists, to consider our attitude not only to the war which is being waged to-day but to war as an expedient for settling the differences between nations. The problems are, in fact, bound up closely together, for among the issues in this war of opposed and utterly irreconcilable philosophies not the least important is that which divides those who believe in war as a virtue and favor political and economic systems that turn this virtue into a recurrent necessity from those who regard war as a barbarism and the eradication of the causes of war as the supreme duty of civilized men and women. By the time these lines are published it is possible that we may all be a little more concerned with the impact of war on our personal lives than with its influence on the numbers and transmissible qualities of generations yet unborn; but at this eleventh hour we may still take a long-term view, fortified in our apparently academic reflections by the knowledge that upon our conclusions on the wider issue will depend in large measure the resolution, steadfastness and spiritual conviction with which we shall face our immediate peril.

The view that war is not necessarily dysgenic, indeed, that it may actually favor the survival of the best physical and intellectual types, is argued ably and with a commendable absence of dogmatism in a letter published elsewhere in this issue. The author suggests that war, being in fact "Nature's usual way of solving the problem of which body of organisms is best fitted to survive within a certain set of circumstances," may be equated with natural selection, and asks how an expedient which ensures the survival of "the nation possessing the best brains and the best bodies" can properly be described as dysgenic. . . .

It is not necessary to consider in detail the points at which the analogy between war and natural selection breaks down. The survival of the fittest does not mean the survival of the best; it means the survival of those who are best adapted to the conditions of their environment. When man and pathogenic bacteria occupy the same ecological system, the death of the former and the survival of the latter is indubitably an instance of the survival of the fittest; but only on the most gloomy view of human nature could it be regarded as satisfactory proof of the survival of the best. Biologically speaking, the term fittest is meaningless except in relation to some particular environment, natural or social. In a world which regards war as desirable and its frequent occurrence as inevitable, the more aggressive and insensitive types have the best chances of ultimate survival. They are able to devote themselves to the congenial tasks of perfecting the weapons of destruction, while their more imaginative and gentler neighbors engage in the suicidal occupation of adding to the amenities and fullness of life. But though, unhappily, all this must be conceded it is not less true that the creation of a world in which love and virtue have a greater survival value than hatred and brutality is still within our power.—*The Eugenics Review* (*London*).